Economics of Reducing Greenhouse Gas Emissions in South Asia

Options and Costs

Financed under ADB-Australia South Asia Development Partnership Facility

ADB

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Foreword

The major challenge for the Asian Developing Member Countries (DMCs) is how to achieve sustained and rapid economic growth for alleviating poverty while reducing the overall intensity of energy use, increasing energy efficiency, and moving to cleaner energy forms. In this context they need to examine their resource and energy options in order to develop a low-carbon path that can also provide sustained, high economic growth and abate greenhouse gas (GHG) emissions at low or even negative costs, and provide other benefits such as energy security, improved health, and more employment opportunities.

South Asia, which is home to the majority of world's poorest people, is expected to bear a significant share of the consequences of the global impacts associated with climate change. Against a backdrop of continuing increase in the emission of GHGs, the South Asia DMCs of the Asian Development Bank (ADB) have been witnessing a steady rise in energy demand and consumption, keeping pace with their economic growth and development aspirations. This trend is likely to continue, although still lower than in neighboring Southeast Asia or developed countries as a whole.

ADB has launched a series of studies on the economics of climate change across Asia and the Pacific, with the first report on Southeast Asia published in 2009. The present study, on the Regional Economics of Climate Change in South Asia (RECCSA), examines the economics of (i) cleaner technologies that promote low-carbon development and climate change mitigation (Part 1), and (ii) adaptation to climate change impacts (Part 2). The first part, which was implemented through technical assistance on *ADB-Australia South Asia Development Partnership Facility*, examined the options and costs of resource- and energy-efficient technologies to mitigate GHG emissions; identified constraints and barriers to clean technology development; and outlined recommended actions and enabling conditions to overcome the challenges. This report synthesizes the results of national studies under Part 1 conducted in five South Asia DMCs—Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka. India was not included because there have been a number of recent studies on its GHG emissions reduction and clean technology potentials, which were used as information and references in this report. The results of the part 2 study will form a separate report.

The study suggests that the annual energy-related GHG emissions in the five countries are together set to rise more than four-fold from 58 million tons of carbon dioxide equivalent in 2005 to 245 million tons in 2030, while primary energy use by 2030 is likely to be almost 3,600 petajoules, 2.4 times higher than in 2005, largely due to rising consumption by industry and transport. The report also reveals excellent opportunities in low-carbon green growth by adopting resource- and energy-efficient technologies that would lower

GHG emissions at a low cost or even cost savings (benefits). At a cost of up to $10 per ton, nearly 20% annual reduction can be achieved by 2020. Introduction of a carbon tax could spur greater use of cleaner energy sources like natural gas, hydropower, biomass, municipal solid waste, and wind, and could reduce total GHG emissions by more than a fifth up to 2030. These are striking results on GHG emissions and the costs and benefits of reducing them in the five South Asia DMCs.

The study's findings and conclusions on the feasibility of designing systems and processes for reducing GHG emissions across sectors are seen as an opportunity for South Asian countries to move toward low-carbon economies, while playing a part in a global solution to climate change. Many funding sources and initiatives, though not adequate, are already available that could help South Asia DMCs build climate resilient and low-carbon economies. ADB will continue to do its part to support the Asian DMCs with knowledge, technologies, and finance in their response to climate change. In 2009, ADB developed a climate change implementation plan that sets out the strategy and investment priorities in South Asia DMCs. It supports adaptation and mitigation efforts in the transport, energy, urban, water supply and sanitation, and agriculture and natural resources sectors. In 2011, approvals of loans and grants by ADB for climate change adaptation and mitigation measures reached $1.039 billion, in a total investment of $2.300 billion.

The report was prepared under the direction of Juan Miranda, Director General, South Asia Department. Sekhar Bonu, Director of South Asia Regional Cooperation and Coordination Division and Hans Carlsson, Head of Portfolio, Results and Quality Control Unit, provided supervision to the study team. Mahfuzuddin Ahmed, Principal Climate Change Specialist, led the finalization and publication of this synthesis report. Experts (consultants) Ram Manohar Shrestha and Rodel Lasco led the modeling work on energy and non-energy related activities, respectively. Tasneem Mirza and Supachol Suphachalasai, Economists, coordinated the consultant inputs. Several ADB staff were involved in the implementation of the technical assistance under which the study was carried out. They include Juzhong Zhuang, Deputy Chief Economist; Bruno Carrasco, Director; and Ngyong Cuong, Hui Phing, and Ruzette Mariano. Jay Maclean edited the publication, with assistance from consultants Roberta Gerpacio and Haezel Barber. Pia Corrina Reyes and consultant Anna Blesilda Meneses coordinated the publication process.

We are grateful to the Government of Australia for financing the regional technical assistance. We recognize the support and cooperation of the concerned governments in the conduct of this study. We also acknowledge the experts, specialists, and scientists who provided the technical inputs and advice for the study. We hope that the information and knowledge gained through this study will help Asian DMCs in their quest for ways to reduce GHG emissions and to move toward low-carbon green growth.

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Abbreviations

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre (Nepal)
ASEAN	Association of Southeast Asian Nations
BIGCC	biomass-based, integrated gasification, combined cycle
CAGR	compounded annual growth rate
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CEC	certified emission credits
CER	certificate of emission reduction
CFL	compact fluorescent lamp
CH_4	methane
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DMC	developing member country
ECHAM5	European Center Hamburg Model-5
FIT	feed-in tariff
GBI	generation-based incentive
GCM	general circulation model
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GLOF	glacial lake outburst floods
IAC	incremental abatement cost
IACC	incremental abatement cost curve
IDCOL	Infrastructure Development Company Limited (Bangladesh)
IPCC	Intergovernmental Panel on Climate Change
IREDA	Indian Renewable Energy Development Agency
LED	light-emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LUCF	land-use change and forestry
LV	light vehicle
MARKAL	market allocation
MSW	municipal solid waste
NOx	nitrogen oxide
N_2O	nitrous oxide
PFBC	pressurized fluidized bed combustion
PPP	purchasing power parity
PRC	People's Republic of China
PV	photovoltaic

R&D	research and development
REC	reduced emission certificate
RECCSA	Regional Economics of Climate Change in South Asia
REPO	renewable energy purchase obligation
SO_2	sulfur dioxide
TERI	The Energy and Resources Institute
TFEC	total final energy consumption
TPES	total primary energy supply
UMMB	urea-molasses multi-nutrient block
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UTS	urea-treated straw
VAT	value-added tax

Weights and Measures

cm	centimetre
GJ	gigajoule
GW	gigawatt
GWh	gigawatt-hour
ha	hectare
kg	kilogram
kg/m^3	kilogram per cubic meter
KJ	kilojoule
ktoe	thousand tons of oil equivalent
kV	kilovolt
KWh	kilowatt-hour
m^3	cubic meter
m	meter
mm	millimeter
MW	megawatt
MWh	megawatt-hour
PJ	petajoule
ppmv	parts per million by volume
t	ton
TJ	terajoule
toe	ton of oil equivalent
TWh	terawatt-hour

Executive Summary

The Asian Development Bank (ADB) South Asia developing member countries (DMCs), comprising Bangladesh, Bhutan, India, the Maldives, Nepal, Sri Lanka, had a combined population of around 1.4 billion in 2011, with about 33% (465.5 million) living below the $1.25 (PPP) per day poverty line, or about 6.7% of the global population (ADB 2011). The region is considered vulnerable to the impacts and consequences of climate change, including sea level rise in Bangladesh, India, the Maldives, and Sri Lanka; melting Himalayan glaciers in Bhutan, India, and Nepal; and increased frequency of typhoons, particularly in Bangladesh. Notwithstanding these challenges, sustained and rapid economic growth is necessary for the region to achieve significant poverty reduction, uplift the economic well-being of its people, and increase its resilience to environmental shocks and natural disasters, including those associated with climate change.

Against a backdrop of continuing increase in the emission of greenhouse gases (GHGs) that are responsible for global climate change, energy consumption and use of fossil fuels in South Asia DMCs are growing rapidly. In 2030, the total primary energy use in Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka could be 2.4 times that in 2005. In India, total commercial energy consumption in 2031 could be 5.4 times that in 2006, although there are large variations in estimates of future energy growth across studies. The countries need a new look at their resource and energy options in order to develop a low-carbon path that can provide sustained high economic growth and simultaneously abate GHG emissions.

This report synthesizes the results of studies conducted under an ADB technical assistance on the Regional Economics of Climate Change in South Asia Phase 1 (RECCSA 1) in five countries (Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka). The studies estimated the likely growth of GHG emissions to 2030 under a scenario of expected energy-use mixes, including penetration of some clean technologies, and the impact of a climate policy in the form of a carbon tax to stabilize GHG production at an acceptable level. The studies used a sophisticated market allocation modeling (MARKAL) approach to examine two scenarios: (i) the base case, which considers energy system development without any climate policy interventions during 2005–2030; and (ii) the carbon-tax scenario, which analyzed the evolution of the energy mix, electricity generation system, GHG emissions, and energy system cost under an alternative climate policy (in the form of a carbon tax/carbon price) for achieving the global stabilization target of carbon dioxide (CO_2) concentration. The analyses on India were based on existing literature.

Without any climate policy interventions (under the base case), South Asia would become increasingly carbon intensive during 2005–2030. The consumption of fossil fuel would grow by over fivefold in India and over threefold in the other five countries as a group, with similar increases in the use of imported natural gas. The significant growth of coal use in the region would however be of particular concern. The transport sector is the fastest growing in terms of energy consumption in South Asia over the study period, mainly due to its very high growth in India.

Total power generation capacity in the five countries of South Asia (without India) would increase by 256% during 2005–2030 in the base case, and would be 3.26% higher with the carbon tax. The total investment requirement for power generation in the five countries in the 25-year period would be similar in the two cases at around $104 billion.

The total energy-related GHG emissions in the five South Asian countries (without India) would be 3.2 times higher in 2030 than that in 2005 in the base case. Power generation, industry, and transport would be the three major contributors, with emissions from the power sector increasing during the period.

In a carbon tax regime that is considered necessary to stabilize GHG concentration at 550 parts per million by volume (ppmv) of carbon dioxide equivalent (CO_2e), the primary energy mix of the five South Asian countries (without India) would move toward more aggressive use of cleaner resources, i.e., natural gas, hydropower, biomass, municipal solid waste, wind, and nuclear energy. The total consumption of coal and petroleum in 2030 would be 68.0% and 2.1% lower than that in the base case, respectively. There would also be a cumulative reduction in energy-related GHG emissions by around 971 million tons (t) of CO_2e during 2005–2030, as compared to the cumulative GHG emission of 4,011 million t of CO_2e during the same period in the base case. The total annual energy-related GHG emissions in the five countries would decrease by 6.1% (8.4 million t CO_2e) by 2020 and by 22.0% (53.8 million t CO_2e) by 2030.

At the country level, the carbon tax would reduce cumulative GHG emissions by 9.4% in Bangladesh and 21.8% in Sri Lanka. However, its effect would be minimal in Bhutan and Nepal, where biomass and hydropower are the main sources of energy; and in the Maldives, where the availability of major renewable energy sources (biomass, wind, and hydropower) is very small.

Not all cleaner options are expensive. The study found a number of clean technology options that are cost-effective even without any climate policy interventions. These technologies range from energy-efficient lamps, air conditioners, and solar and electrical cooking stoves in residential and commercial sectors, energy-efficient electric motors and diesel boilers in industrial sector, efficient diesel tractors in agriculture to partial modal shifts in the road freight to railways in the transport sector. GHG abatement cost analysis shows that a total reduction potential of about 13.3 million t CO_2e emissions could be achieved in 2020 in the five countries at no additional cost, by deploying "no-regret" clean and energy-efficient options. In the same year, around 27.9 million t CO_2e (20.1% of the base case emission) could be abated at the incremental abatement cost (IAC) of up to $10 per ton of CO_2e, with most of the total GHG reduction coming from the power sector.

For activities not using energy in South Asia (without India and the Maldives), GHG emissions from agriculture, industrial processes, and waste generation are estimated to nearly double in 2005–2030, with crop production having the dominant share (50%–52%). In addition, carbon sink (sequestration) capacity of the forestry sector is estimated to decline by about 15%. Among the abatement options considered for activities not using energy, the following offer the highest potential abatement capacities at reasonable per-ton IACs: (i) agriculture: urea-molasses multi-nutrient block supplementation for dairy cattle; and intermittently-irrigated rice land under single aeration; (ii) forestry: conservation of the existing carbon sink; (iii) waste management: composting of solid waste; and (iv) industrial processes: addition of capacity of cement plants fitted with post-combustion carbon capture and storage technology.

While it is crucial for South Asian countries to reduce energy-related GHG emissions per unit of their GDPs over the next two decades, policy and regulatory barriers, perverse subsidies on conventional fossil fuels, and uncertain future carbon prices currently reduce incentives to invest in large-scale development of clean energy resources and GHG emission-reducing technologies. Access to technologies and innovative and affordable finances are also limiting factors for investments in technologies with low IACs.

Overall, technology access, policy and financing issues will continue to influence the development of clean technologies and move toward low-carbon growth in South Asia. Large-scale development of clean energy resources to significantly reduce carbon intensity and GHG emissions will be crucial. This can be achieved by South Asian countries by prioritizing investments in technologies across sectors with low IACs and other co-benefits, such as reducing emissions of other locally-damaging pollutants and providing economic opportunities for communities. The scope of these investments can cover (i) promotion of energy efficiency and development of renewable energy; (ii) low-carbon transport infrastructure; (iii) urban services, including employing cost-effective and income-generating waste management mechanisms; (iv) energy-efficient buildings and other infrastructure; and (v) energy-efficient irrigation pumps, including use of solar energy. Regional energy cooperation and trade as well as south-south and north-south cooperation on technology and knowledge sharing will pave the way for a move towards low-carbon and green development in South Asia.

1 Introduction

The Asian Development Bank (ADB) South Asia developing member countries (DMCs), comprising Bangladesh, Bhutan, India, the Maldives, Nepal, Sri Lanka, had a combined population of around 1.4 billion in 2011, with about 33% (465.5 million) living below the $1.25 (PPP) per day poverty line, or about 6.7% of the global population (ADB 2011). The region is also considered vulnerable to the impacts and consequences of climate change, including sea level rise in Bangladesh, India, the Maldives, and Sri Lanka; melting Himalayan glaciers in Bhutan, India, and Nepal; and increased frequency of typhoons, particularly in Bangladesh. Notwithstanding these challenges, sustained and rapid economic growth is necessary for the region to achieve significant poverty reduction, uplift the economic well-being of its people, and increase its resilience to environmental shocks and natural disasters, including those associated with climate change.

While greenhouse gas (GHG) emission in South Asia is historically low, rapid urbanization and industrialization are pushing it toward a more carbon-intensive development path. South Asia currently shows an increasing demand for motorized transport and electricity, hence also for imported fossil fuel, making it vulnerable to price volatilities and supply instability in the international markets. The countries in South Asia would need to examine their resource and energy options in order to pursue green-growth strategies and adopt a low-carbon development path, for more inclusive and sustainable economic growth. The identification, promotion, and utilization of clean technologies and renewable energy resources play a crucial role in achieving these goals.

This report synthesizes the detailed analysis of the technical assistance on the Regional Economics of Climate Change in South Asia Phase 1 (RECCSA1) that was conducted in five ADB South Asia DMCs—Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka, with India's rich literature of numerous relevant studies exhaustively used as information and reference. The regional study attempted to identify potential energy and non-energy-related clean technologies and options, estimate their benefits in terms of GHG abatement and co-benefits, and evaluate feasible options and measures at different (or selected) carbon price scenarios. With these information, it aims to help the regional and national decision makers reach a consensus to promote the access to and utilization of clean technologies and options, and establish the region's contribution to global efforts, for addressing climate change.

The second chapter provides a brief profile of South Asia's socioeconomic development; energy resource potential, production and use; and activities not producing energy (agriculture, forestry, and land-use change). It also presents observed and projected climate change and its emerging impacts in the region. Chapter 3 discusses the methodology used to project, for 2005–2030, GHG emissions from activities using energy (hereafter referred to as the “energy sector”) and activities not using energy (the “non-energy sector”). Chapter 4 provides the options and costs of reducing these emissions. Chapter 5 presents the challenges to and enabling policies for the adoption of clean technologies in the region, and the last chapter offers recommendations for the further development and promotion of clean energy resource options and technologies in SouthAsia.

2 Regional Overview

Socioeconomic Background

In this study, South Asia comprises six countries: Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. The region has highly diverse and rich ecological zones, from the Himalayan range that hosts the highest peak in the world, Mount Everest in Nepal, to the coral reef islands of the Maldives. With a total land area of about 3.38 million square kilometers (2.57% of the world total), the region was home to 1.378 billion people (20% of the world population) in 2010 and has the highest population density in the world (World Bank 2012). India's population comprises about 85.8% of the regional total. Its population growth rate of 1.56% (in 2010) is bound to increase the pressure on the natural resources and environment. The region's expanding urban areas and increasing urban population—29.3% of the total in 2010—further contribute to this pressure (ADB 2011). The region is very rich in natural resources, especially water, but scores very low in socioeconomic indicators. Alongside its economic, demographic, and social characteristics, its unique geographic and climatic conditions make South Asia one of the world's most vulnerable regions to climate change impact.

During 2005–2010, South Asia posted good economic growth, with a regional gross domestic product (GDP) that grew at 7.9% per annum (Table 1). In the same period, its per capita real GDP in purchasing power parity (PPP, at constant 2005 international $) grew at a compounded annual growth rate of 8.45%. As in any other region, South Asian countries saw mixed growth rates in the six-year period. The region is led by India with an 8.5% growth rate in 2010.

The agriculture and industry sectors together account for over 40% of GDP in most countries in South Asia, while the service sector has the highest share in GDP (Table 1). The contribution of agriculture to GDP generally declined across the region between 2005 and 2010, and that of industry increased. The Maldives has limited scope for expansion of its agriculture sector and tends to be heavily dependent on the service sector.

Energy Resources, Production, and Use

Energy Resource Potentials

The endowment of energy resources varies widely across South Asia. India has abundant coal resources and Bangladesh has a modest deposit of natural gas and some coal reserves. Bhutan, the Maldives, Nepal, and Sri Lanka have no appreciable fossil fuel reserves. The region has no indigenous oil resources, except for small reserves in India

Table 1 **Selected Social and Economic Indicators of South Asian Countries**

Indicators	Bangladesh		Bhutan		India		The Maldives		Nepal		Sri Lanka		World	
	2005	2010	2005	2010	2005	2010	2005	2010	2005	2010	2005	2010	2005	2010
Population (million)[a]	137	146.2	0.6	0.7	1,101	1,182.1	0.3	0.3	24.9	28.9	19.6	20.7	6,506	6,895
Population growth rate (%)[a]	1.3	1.3	1.3	1.8	1.5	1.4	1.5	1.7	2.3	2.2	0.9	1.0	1.2	1.1
% Urban population[a]	25.7	28.1	31.0	34.7	28.7	30	33.8	40.1	15.9	18.6	14.7	14.3	28.7	30.0
GDP per capita, PPP (constant 2005 $)[b]	1,195	1,488	3,552	4,780[c]	2,286	3,039	5,248	7,387	1,045	1,079	3,550	4,601	2,286	3,535
Growth rate of real GDP[a]	6.0	5.8	7.0	6.7	9.5	8.5	(7.1)	9.9	3.5	4.6	6.2	8.0		
Sector contribution to GDP (%)[a]														
Agriculture	20.1	18.8	23.3	18.7	18.8	19.0	7.7	5.3	35.2	35.0	13.5	12.8		
Industry*	27.2	28.5	36.6	42.0	28.1	26.3	15.5	12.4	17.1	15.0	32.2	29.4		
Services and others	52.6	52.6	40.1	38.1	53	54.7	77.4	82.8	47.7	50.1	54.3	57.8		

( ) = negative, GDP = gross domestic product, PPP = purchasing power parity.

* Includes manufacturing, mining, construction, and electricity, gas, and water.

Sources:
[a] ADB. 2011. *Key Indicators for Asia and the Pacific 2011, 42nd Edition*. Manila.
[b] World Bank. 2012. *World Development Indicators*. http://data.worldbank.org/data-catalog/world-development-indicators, accessed on 21 August 2012.
[c] 2009 data.

and Bangladesh. Bhutan and Nepal—the Himalayan countries—have rich hydropower potential, but no indigenous fossil energy resources. India's hydropower potential is also significant although it may not be considered big given the country's large demand for electricity.

Biomass

Table 2 presents the potential for biomass energy resources (fuelwood, agricultural residues, and animal waste) in South Asia. India has high fuelwood potential because of its large land and forest areas. The total sustainable annual forest yield in Bhutan is equivalent to about 3.9 million tons (t), of which only 40% (about 1.57 million t) is estimated to be extractable (RGoB DoE 2007). In Sri Lanka, energy crop plantations to produce bioethanol and biodiesel have the potential to produce 24,000 gigawatt-hours (GWh) per year (Nissanka and Konaris 2010).

The total annual amount of recoverable agricultural crop residues in Bangladesh is about 44.1 million t, of which 60% is field residues and 40% is process residues (Mondal 2010). In Bhutan, the total biomass availability potential from agricultural residues is estimated at 0.308 million t per annum of soft stem residues[1] and 0.058 million t of powdery residues[2] (RGoB DoE 2007). In India, although 388 million t of agricultural residues are available,

[1] Crops with bulk density between 30 kilograms per cubic meter (kg/m^3) and 60 kg/m^3, and which can be baled and compressed like paddy, wheat, barley, mustard, maize, and millet.
[2] Crops with bulk density of about 100 kg/m^3 like paddy husk, maize husk, and cob.

Table 2 **Biomass and Biogas Production Potential and Total Number of Biogas Plants Installed in South Asia**

Country	Reference/Source	Year	Biomass Potential (million tons) Fuelwood	Agricultural Residues	Animal Waste	Theoretical Annual Biogas Production Potential[h] (million cubic meters)	Total No. of Installed Biogas Plants
Bangladesh	Mondal (2010)		10.9[a]	44.1	40		22,549
	GPRB MPEMR PD (2012b)					8.60	
Bhutan	RGoB DoE (2007)	2005	3.9	0.366	0.3	8.86	
India	GoI MNRE (2012a)	2011	500				
	GoI MNRE (2012b, 2012c)					15,000[b]	4,404,762[d]
	Sarkar (2007)	2011		388			
The Maldives	ECN (2004a, 2004b)	2005	0.009[e]	0.015[f]	0.023[g]	n.a.	
Nepal	GoN WECS (2010)	2008/2009	12.5	19.4	14.9	1,865.3	
	AEPC (2012a)						256,662
Sri Lanka	FAO (2009)	2011	8.9				
	ADB (2004)	2011		1.96			
	SSEA (2012a)	2011			0.01		
	Nissanka and Konaris (2010)					1,168[c]	

GJ = gigajoule, kg = kilograms, kJ = kilojoule, n.a. = data not available, TJ = terajoule.

[a] Recoverable biomass, calculated considering a 100% recovery rate and unchanging production rate (Mondal 2010).
[b] Calculated from 35 million m^3/day potential.
[c] Calculated from 3.2 m^3/day potential.
[d] Cumulative physical achievements as of 31 March 2011.
[e] Net calorific value of fuelwood is considered to be 14,400 kJ/kg to convert 130 TJ to tons.
[f] Net calorific value of agricultural residue is considered to be 15 GJ/ton to convert 220 TJ to tons.
[g] Net calorific value of animal waste is considered to be 8.8 GJ/ton to convert 200 TJ to tons.
[h] Based on animal waste only.

the net usable amount is only 182 million t (Sarkar 2007). In 2008/2009, Nepal's supply potential of agricultural residues was estimated at 19.4 million t, equivalent to 243 million gigajoules (GJ) of energy (GoN WECS 2010).

Animal waste is the third significant source of potential biomass energy in South Asia, especially in the rural areas. Based on the availability of cattle dung in India, an estimated 12 million units of family-type biogas plants can be installed, to generate an average of about 15,000 million cubic meters (m^3) of biogas annually. As of 31 July 2012, about 4.28 million units (35.7%) had been installed around the country (GoI MNRE 2012a). Nepal has the technical potential[3] to install 1.3 million–2.9 million biogas plants (GoN WECS 2010).

[3] Technical potential is defined as the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints (Source: http://www.nrel.gov/gis/re_potential.html). In other words, technical potential is the theoretical maximum amount of energy use that could be displaced by the technology being evaluated (e.g., energy efficiency, combined heat, and power) disregarding all non–engineering constraints (source: http://www.epa.gov/statelocalclimate/resources/glossary.html).

Hydropower

The total economic hydropower potential[4] in South Asia is estimated at 152,580 megawatts (MW), while the total theoretical potential[5] across three countries (Bhutan, India, and Nepal) is about 264,000 MW (Table 3). Both parameters vary widely among the countries in the region, from negligible in the Maldives to 149,000 MW and 84,040 MW, respectively, in India.[6] However, although India has the highest exploitable theoretical hydropower potential in absolute terms, it ranks only third in per capita terms, after Bhutan and Nepal (in that order).

Nepal envisioned developing its hydropower potential over several 5-year periods: 2,057 MW in 2009–2013; 12,423 MW in 2014–2019; 5,114 MW in 2020–2024; and 18,034 MW in 2025–2029 (GoN MoWR 2009). However, development is severely lagging behind the targets, with the installed hydropower capacity in the country being 652 MW, as of 2011, i.e., only 1.6% of its economic hydropower potential (Table 3). In contrast, Sri Lanka has already developed 70% of its economic hydropower potential and still has scope to develop small hydropower projects that have an estimated potential of 400 MW (SSEA 2012b).

As of 2011, India, Bangladesh, and Bhutan had installed 46.7%, 29.7%, and 6.3% of their economic hydropower potentials, respectively (Table 3). In Bhutan, most of

Table 3 **Theoretical and Economic Hydropower Potential in South Asia**

Country	**Reference/Source**	**Theoretical Hydropower Potential** (megawatt)	**Theoretical Hydropower Potential per Capita** (kilowatt as of 2010)	**Economic Hydropower Potential** (EHP in megawatts)	**Installed Hydropower Capacity** (megawatts as of 2011)	**Installed Hydropower Capacity** (% of EHP)
Bangladesh	GPRB (2011)	n.a.	–	775	230	29.7
Bhutan	RGoB NEC (2011)	30,000	42.86	23,765	1,505.32	6.3
India	GoI MoEF (2012) GoI MPCEA (2012)	149,000	0.13	84,040[a]	39,291.40	46.8
The Maldives		n.a.	n.a.	n.a.	n.a.	n.a.
Nepal	GoN WECS (2011)	83,000	2.87	42,000	652.09	1.6
Sri Lanka	Young and Vilhauer (2003) DSRSL CBSL (2012)	n.a.	n.a.	2,000	1,399	70.0
Total		**264,000[b]**	**0.21**	**152,580**	**43,077.8**	**28.2**

n.a. = not available, – = no data.

[a] at 60% plant factor; [b] for four countries.

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[4] Economic potential is the subset of technical potential that is economically cost–effective (e.g., as compared to conventional supply-side energy resources). Estimates of economic potential do not address market barriers to implementation (Source: http://www.epa.gov/statelocalclimate/resources/glossary.html).

[5] Theoretical potential is the annual energy potentially available in the country if all natural flows were turbined down to sea level or to the water level of the border of the country (if the watercourse extends into another country) with 100% efficiency from the machinery and driving waterworks.

[6] In India, the estimated potential for power generation from small hydropower projects (i.e., projects up to 25-MW capacity) is 15,380-MW (GoI MNRE 2012a).

this hydropower is exported to India, and the government aims to generate a total of 10,000 MW by 2020 (RGoB NEC 2011).

Wind

Except for India, countries in South Asia have little or no reliable data for a comprehensive assessment of wind energy potential, and are only beginning to collect reliable wind speed data for mapping their wind energy resources. Table 4 presents the limited information collected in this study, and shows that India leads in terms of wind power (as well as solar and coal-fired power).

India has an estimated total wind potential of 48,561 MW, of which about 36.3% has been installed (as of June 2012). The government aims to produce an additional 2,500 MW of wind power in 2012/2013 (GoI MNRE 2012c).

In Bangladesh, the wind power potential is estimated at 4,614 MW, but only 2% (92.3 MW) is considered technically exploitable because of limited grid access and scattered wind power sites (Mondal 2010). Meanwhile, preliminary assessment in Bhutan gave a wide range of wind energy potential at between 5 MW and 3,670 MW (Gilman, Cowlin, and Heimiller 2009). The total wind potential of the Maldives is yet to be assessed (NREL 2008), while that of Nepal was reportedly not high (GoN WECS 2010).

Table 4 **Wind Power, Solar Power, and Coal Resources in South Asia**

Country	Reference/ Source	Wind Power (MW)		Technical Solar Power Potential (MW)	Coal Reserves (ton)	Installed Coal-Fired Power Plants (MW)
		Potential	Installed			
Bangladesh	Mondal (2010)	4,614	92.3	50,175		
	GPRB EMRD (2012)				3.3 billion	250
Bhutan	Gilman, Cowlin, and Heimiller (2009)	5–3,670		91 million kWh		
	RGoB NEC (2011)				1.96 million	
India	GoI MNRE (2012b)	48,561	17,644			
	GoI MoC (2011)				114 billion	116,333
The Maldives	NREL (2008)			793 MWh/year		
Nepal	AEPC (2008)	3,000	9.2 kW			
	GoN WECS (2010)			2,920 GWh		
Sri Lanka	Young and Vilhauer (2003)	24,000				
	DSRSL CBSL (2012)		3			
	DSRSL MoPE (2012)				0	300

GWh = gigawatt-hour, kWh = kilowatt-hour, MW = megawatt, MWh = megawatt-hour.

Solar Power

South Asia has good solar power resource with solar radiation of 4–7 kilowatt-hour per square meter per day (kWh/m^2/day) in most countries, except in the Maldives and Nepal where it is 3.5–5.0 kWh/m^2/day and 3.6–6.2 kWh/m^2/day, respectively (Young and Vilhauer 2003; Gilman, Cowlin, and Heimiller 2009; GoN WECS 2010; GoI MNRE 2012d; GPRB MPEMR 2012a; SSEA 2012a).

The annual average values of global horizontal solar radiation in Bhutan are 4.0–5.5 kWh/m^2 per day. The country has an estimated total theoretical solar power potential for grid connected photovoltaic systems to be 58,000 MW (DC), an amount equivalent to the annual generation of about 92 million kWh (DC) and 82 million kWh (AC) of electricity (Gilman, Cowlin, and Heimiller 2009). The country also has potential for 50,000 units of 100 watts peak solar power systems, which would have a GHG abatement potential of 8,800 t CO_2 equivalent (CO_2e) (RGoB NEC 2011).

As of June 2012, India's total solar power installed capacity is reported to be 1,030.66 MW (GoI MNRE 2012c), with the government targeting 800-MW of solar power in 2012/2013. The realizable techno-economic potential for solar-powered water heating systems in India is estimated at 40 million m^2 of collector area, of which nearly 5 million m^2 had been installed as of 2011 (GoI MNRE 2012b).

In Nepal, the theoretical annual solar power potential was estimated at 2,920 GWh (GoN WECS 2010), with the commercial potential for grid-connected solar power estimated at 2,100 MW (AEPC 2008). By 2011, a total of 64,300 solar home systems based on photovoltaic had been installed in the country (AEPC 2012b).

Coal

As of 2011, the total proven coal reserve in South Asia was estimated at 117.3 billion t, of which 97.2% (114 billion t) was in India.[7] Bangladesh and Bhutan have coal reserves of about 3.3 billion t (GPRB EMRD 2012) and 1.96 million t (RGoB NEC 2011), respectively. No other country in the region has appreciable coal reserves.

As of 2011, South Asia has a total 116,883 MW of installed capacity of coal-fired power plants. This includes India's 116,333 MW, which is 56.6% of its total installed power generation capacity (GoI MoC 2011), and Bangladesh's 250-MW coal-fired power plant in Boropukuria mine (GPRB 2011).

Sri Lanka has no coal resources, but has begun adding coal-based power generation capacity into the national grid using imported coal. Up to 300 MW in coal-fired power plants were installed by 2011, with another 600 MW being installed (DSRSL MoPE 2012).

Oil

Bhutan, the Maldives, and Nepal have no oil reserves and are fully dependent on imported oil supply. Sri Lanka has identified commercial-level potential oil reserves and proven oil reserves (the latter only in 2011). However, the country continues to rely on imports for its petroleum requirements (DSRSL CBSL 2012).

[7] This is about 40% of the total coal resource potential identified in India (GoI MoC 2011).

Bangladesh, with only about 8 million t of proven oil reserves (Uddin 2006 as cited in Mondal 2010), imported 1.2 million t of crude oil and 2.6 million t of refined petroleum products in 2010 (GPRB 2011).

In 2010–2011, India's recoverable crude oil reserve was estimated at 757.4 million t, which was still not adequate to meet the country's growing energy requirements (GoI MPNG 2011). In the same period, India imported 163.5 million t of crude oil (about 79.3% of total consumption), 8.95 million t of liquefied petroleum gas (LPG), and 17.3 million t of petroleum products (GoI MPNG 2011).

Natural Gas

Natural gas is an important source of energy for Bangladesh and India. Bangladesh has a total extractable reserve of around 20.5 trillion cubic feet, of which about 9.4 trillion cubic feet had been utilized as of December 2011. Of the 23 natural gas fields discovered across Bangladesh, 17 fields are under active production (GPRB 2011).

India's recoverable natural gas reserve has been estimated at 1,241 billion cubic meters (m^3). Gross production in 2010–2011 was 52.2 million m^3, which was almost 10% higher than that in 2009–2010. Despite the steady increase, demand outstrips supply, and the country has been a net importer since 2004. Net imports of natural gas reached an estimated 429 billion cubic feet in 2010 (GoI MPNG 2011).

Energy Production and Use

The energy economy in South Asian countries is characterized by low levels of electricity access, per capita electricity consumption, and per capita modern energy consumption; relatively high dependence on biomass energy; and growing dependence on imported fossil fuels, especially petroleum products.

Total Primary Energy Supply

Table 5 presents the overall structure of the total primary energy supply (TPES) in South Asia for 2005 and 2009. TPES increased by 15.6% in South Asia, including India, during this period, and at 25% excluding India. Supply increased at a compounded annual growth rate of 5.9% in India, 5.2% in Bangladesh, and 3.7% in Nepal in the same period (IEA 2011). At the regional level, the share of coal and natural gas in the TPES increased, while that of biomass and hydropower decreased.

As expected, the countries in South Asia show a large difference in their energy supply mix. Fossil fuels dominate the TPES of Bangladesh, India, and the Maldives, while renewable energy sources (mainly biomass and hydropower) are dominant in Bhutan, Nepal, and Sri Lanka (Table 5). Coal is the single largest energy resource used in India, while it is natural gas in Bangladesh and petroleum products in the Maldives (which depends almost entirely on oil). During 2005–2009, Bangladesh and India showed a growing dependence on natural gas, and the rest of the region on petroleum products.

Based on per capita indicators, TPES across South Asia increased from 0.45 t of oil equivalent (toe) in 2005 to 0.53 toe in 2009 (Table 6), which is 70% less than the global figure of 1.8 toe. TPES per capita increased in all countries between 2005 and 2009,

Table 5 **Structure of Total Primary Energy Supply in South Asia, 2005 and 2009**

	Bangladesh		Bhutan[a]		India		The Maldives[b]		Nepal		Sri Lanka		South Asia including India		South Asia excluding India	
Indicators	**2005**	**2009**	**2005**	**2009**	**2005**	**2009**	**2005**	**2008**	**2005**	**2009**	**2005**	**2009**	**2005**	**2009**	**2005**	**2009**
TPES (toe)	24.2	29.6	0.4	n.a.	537	675.8	0.2	0.3	8.6	9.9	9.0	9.3	579.5	725.0	42.4	49.1
Energy resource share in TPES (%)																
Biomass	34.3	29.8	57.6	n.a.	29.7	24.8	1.3	0.2	87.5	86.2	52.9	51.0	31.1	26.2	49.0	45.0
Coal	1.4	2.1	6.8	n.a.	39.1	42.7	0.0	0.0	2.0	1.9	0.7	0.6	36.3	39.9	1.8	2.4
Petroleum products	19.1	15.9	19.9	n.a.	24.2	23.9	98.7	99.8	8.3	9.1	43.2	44.7	24.1	23.7	22.2	20.6
Natural gas	44.7	51.8	0.0	n.a.	5.4	7.3	0.0	0.0	0.0	0.0	0.0	0.0	6.9	8.9	25.3	30.7
Hydropower	0.5	0.4	15.8	n.a.	1.6	1.3	0.0	0.0	2.2	2.7	3.2	3.6	1.6	1.3	1.6	1.3

n.a. = not available, toe = ton of oil equivalent, TPES = total primary energy supply.

Sources

IEA (International Energy Agency). 2011. *World Energy Outlook 2011*. Paris.

[a] 2005 data from RGoB DoE (Royal Government of Bhutan, Department of Energy). 2007. *Bhutan Energy Data Directory 2005*. Ministry of Trade and Industry. Thimphu.

[b] RoM MMA (Republic of the Maldives, The Maldives Monetary Authority). 2011. *Annual Economic Review 2010*. Malé. http://www.mma.gov.mv/ar/ar10.pdf?bcsi_scan_9688b637a46568db=0&bcsi_scan_filename=ar10.pdf

except Bangladesh and Sri Lanka. The Maldives posted the largest increase. Similarly, fossil fuel consumption and electricity use increased across the region, except in Sri Lanka. The region's per capita electricity consumption of 2,045 kWh in 2009 was 25% lower than the global average of 2,730 kWh (IEA 2011).

A country's energy intensity of GDP is defined as its energy use (i.e., TPES) per unit of GDP, which provides a picture of the economy's energy use efficiency, i.e., the amount of energy required per dollar of GDP. (To compare across countries, GDP in constant 2005 PPP was applied in this study.) South Asia's energy intensity of GDP declined from 0.21 toe/PPP $1,000 in 2005 to 0.18 toe/PPP $1,000 in 2009, which was comparable to the global average of 0.19 toe/PPP $1,000 (Table 6). Similarly, the region's electricity use per unit of GDP declined but fossil fuel use per unit of GDP increased during 2005–2009.

Structure of Electricity Production

As of 2011, the total installed electricity generation capacity in South Asia was estimated at 218,895 MW (Table 7). It ranged from 106 MW in the Maldives to more than 205,000 MW in India, which is about 93.8% of the region's total capacity. Energy composition was 53.2% coal, 19.7% hydropower, and 13.5% oil and gas.

Oil and gas-powered sources comprised the majority of installed electricity generation capacity in Bangladesh (95%) and Sri Lanka (54%), while hydropower sources dominated in Bhutan (99%) and Nepal (92%). In India, coal contributed the most (57%) to total electricity generation capacity, followed by hydropower sources at 19%. The Maldives is totally dependent on oil and gas for electricity generation and only India has a nuclear-powered electricity generation system installed.

Table 6 **Energy Indicators in South Asia, 2005 and 2009**

Indicators	Bangladesh		Bhutan		India		The Maldives		Nepal		Sri Lanka		South Asia including India	
	2005	2009	2005[a]	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
TPES per capita (toe)	0.2	0.2	0.63	n.a.	0.49	0.58	0.75	1.10	0.35	0.36	0.46	0.45	**0.45**	**0.53**
Fossil fuel consumption per capita (toe)	0.07	0.08	0.17	n.a.	0.14	0.19	0.74	1.10	0.04	0.04	0.15	0.13	**0.13**	**0.17**
Electricity use per capita (kWh)	133	250	1,052	n.a.	434	602.2	1,686	1,777	71	96	370	357	**1,926**	**2,045**
TPES/GDP at PPP (toe per constant 2005 $1,000)	0.15	0.13	0.18	n.a.	0.21	0.18	0.14	0.15	0.33	0.31	0.13	0.10	**0.21**	**0.18**
Fossil fuel/GDP at PPP (toe per constant 2005 $1,000)	0.06	0.05	0.05	n.a.	0.06	0.06	0.14	n.a.	0.04	0.03	0.11	0.10	**6.61**	**9.21**
Electricity use/GDP at PPP (kWh per constant 2005 $1,000)	111	163	280	n.a.	190	186	1,276	897	68	82	104	77	**898**	**685**

GDP = gross domestic product, kWh = kilowatt-hour, n.a. = not available, PPP = purchasing power parity, toe = ton of oil equivalent, TPES = total primary energy supply.

Sources:
IEA (International Energy Agency). 2007. *World Energy Outlook 2007, [the People's Republic of] China and India Insights*. OECD/IEA. Paris.
IEA (International Energy Agency). 2011. *World Energy Outlook 2011*. Paris.
[a] RGoB DoE (Royal Government of Bhutan, Department of Energy). 2007. *Bhutan Energy Data Directory 2005*. Ministry of Trade and Industry. Thimphu.

Table 7 **Structure of Installed Electricity Generation Capacity in South Asia, 2011** (MW)

Country	Reference/Source	Coal	Oil and Gas	Nuclear	Hydropower	Other Renewables	Total
Bangladesh	BPDB (2011)	200	7,679	0	220	0.018	8,099
Bhutan	RGoB DoE (2011)	0	20	0	1,486	0	1,505
India	GoI MPCEA (2012)	116,333	20,103	4,780	39,291	24,833	205,340
The Maldives	Sankar et al. (undated)	0	106	0	0	0	106
Nepal	GoN NEA (2011)	0	53.4	0	652.1	0.1	706
Sri Lanka	DSRSL CBSL (2012)	0	1,690	0	1,399	50	3,139
Total		116,533	29,651	4,780	43,048	24,883	218,895
% Total		53.2	13.5	2.2	19.7	11.4	100.0

Note: Other renewables include geothermal, solar, wind, and others.

Energy Consumption by Sector

Table 8 presents South Asia's total final energy consumption (TFEC) and sector shares in 2009. TFEC in the region increased at 5.6% per year in 2005–2009, with the share of electricity in TFEC increasing from 11% in 2005 to 13.5% in 2009. The residential sector accounted for the largest share in TFEC, followed by the industrial and transport sectors.

Table 8 **Total Final Energy Consumption by Sector, South Asia, 2009** (%)

Sectors	Bangladesh	Bhutan[a]	India	The Maldives	Nepal	Sri Lanka	South Asia, including India	South Asia, excluding India
Total final energy consumption (ktoe)	23,135	2,395	449,270	n.a.	9,878	8,010	492,688	43,418
Agriculture	5.0	1.2	3.8	n.a.	1.4	0.1	3.7	3.1
Commercial	1.6	10.3	3.3	n.a.	1.6	3.9	3.2	2.5
Industrial	21.1	25.2	30.4	n.a.	3.6	26.7	29.3	18.3
Residential	52.0	49.0	37.6	n.a.	87.7	43.0	39.5	58.3
Transport	11.3	14.4	11.5	n.a.	5.8	23.2	11.5	12.4
Others	0.1	n.a.	4.8	n.a.	0	2.0	4.4	0.4
Non-energy use	8.9	n.a.	8.6	n.a.	0	1.1	8.3	5.0

ktoe = thousand tons of oil equivalent, n.a. = not available.

Note: Bhutan data as of 2005.

Sources:
IEA (International Energy Agency). 2011. *World Energy Outlook 2011*. Paris.
[a] RGoB DoE (Royal Government of Bhutan, Department of Energy). 2010. *Integrated Energy Management Master Plan*. Prepared for Department of Energy, Ministry of Economic Affairs. Thimphu. TERI Press. The Energy and Resources Institute. http://www.nec.gov.bt/nec1/wp-content/uploads/2012/11/EnergyMasterPlan2010.pdf?bcsi_scan_9688b637a46568db=0&bcsi_scan_filename=EnergyMasterPlan2010.pdf

Activities Not Using Energy

Agriculture[8]

Crop Production and Fertilizer Use

The major crops produced in South Asia are rice, maize, wheat, and millet. In Sri Lanka, coconut, tea, and rubber are also important crops. Across the region, rice is the biggest agricultural crop, although its production had the slowest growth at only 0.3% per year during 2000–2010 (Table 9). India accounted for more than 67% of the region's total rice production, 82% of maize, and 97% each of wheat and millet. The Maldives relies most heavily on imported food grains.

South Asia posted a 2.1% annual increase in nitrogen fertilizer use during 2000–2010 (Table 9), mainly to support the need for higher crop production. All countries posted positive annual growth rates in the use of nitrogen fertilizer for agriculture, ranging from Sri Lanka's 1% to 15.2% in the Maldives.

Livestock

In general, South Asia's livestock production has grown much faster than crop production. The populations of buffaloes, cattle, and goats increased by 20%, 9%, and 39%, respectively, during 2000–2010, while pig numbers decreased by 25%. India accounted for 94% of the buffalo population in the region. Table 9 shows the annual growth rates of selected crops and livestock in South Asian countries during 2000–2010.

[8] This section refers to activities in agriculture that emit GHGs without involving energy combustion.

Table 9 **Annual Growth Rates of Selected Crops and Livestock, South Asia, 2000–2010** (%)

Commodity	Bangladesh	Bhutan	India	The Maldives	Nepal	Sri Lanka	South Asia, including India
Paddy rice	2.8	3.4	(0.6)	0.0	(0.5)	4.1	0.3
Maize	56.6	1.3	1.6	3.5	2.8	17.9	2.3
Millet	2.1	3.2	0.8	0.0	1.0	3.9	0.8
Wheat	(6.9)	0.3	0.5	0.0	2.8	0.0	0.5
Nitrogen use for agriculture	3.5	6.1	2.0	15.2	4.3	1.0	2.1
Buffaloes	4.3	(4.0)	1.7	0.0	3.2	3.3	1.8
Cattle	0.3	(1.6)	0.9	0.0	0.2	0.2	0.8
Pigs	0.0	(6.8)	(3.2)	0.0	1.9	1.7	(2.8)
Goats	6.6	2.3	2.2	0.0	3.4	(2.8)	3.3
Chickens	5.6	0.6	8.8	0.0	3.3	2.8	7.8

( ) = negative.
Source: FAO. 2012. FAOSTAT database (accessed 12 August 2012).

Land-Use Change and Forestry

Land Use and Land-Use Change

Nearly 60% (196.5 million hectares [ha]) of the land area in South Asia, including India, is devoted to agriculture and about 23% (78 million ha) are forests (Table 10). Total agricultural area decreased during 2000–2008 and total forest area increased during 2000–2010. Although Bangladesh, Bhutan, and Sri Lanka showed increases, the decline in India's agricultural area by nearly 3 million ha influenced the overall regional trend. Similarly, the increase in forest areas of India and Bhutan overtook the respective decreases in Bangladesh, Nepal, and Sri Lanka. India's agricultural and forest areas are about 91% and 87% of the regional total. Except for Nepal and Sri Lanka, the use of land for other purposes (i.e., fields, pastures, and settlements) appears to have generally decreased in South Asia.

Forests and Forest Resources

As a proportion of the country's total land area in 2010, forest cover in the region was highest in Bhutan and lowest in the Maldives. Across the region, 21% of the total forest area was primary forest. However, Bangladesh, Nepal, and Sri Lanka posted significant deforestation during 2000–2010 (Table 11). While India has exerted considerable effort to increase its forest area, Nepal and Sri Lanka both face massive deforestation—seemingly of their primary forests—due to fuelwood harvesting and conversion of land for agriculture. On average, around 10,000 ha of primary forest per year was put to other land uses during 2000–2005. To compensate for this, forest plantations in South Asia increased from 7.7 million ha in 2000 to 10.7 million ha in 2010, with India contributing the most increase. The region's forest plantation area remains in decline when India is excluded from the analysis.

As expected, the 2010 estimated carbon stock in forest biomass was highest in India at 2,800 million t, and lowest in Sri Lanka at 61 million t (Table 11). On a per-hectare basis, Nepal and Bhutan have the highest carbon stocks in forest biomass, and Sri Lanka and

Table 10 **Selected Land-Use Indicators in South Asia, 2000 and 2010[a]**

Country/Year	**Total Land Area** (million hectare)	Land Use as % of Total Land Area: **Agriculture[b]**	Land Use as % of Total Land Area: **Forest**	Land Use as % of Total Land Area: **Others**	**Coastline** ('000 km)
Reference	ADB (2011)	ADB (2011)	FAO (2010)	Authors' estimates	ADB (2011)
Bangladesh	13.0				0.6
2000		69.8	11.5	18.7	
2010		71.4	11.1	17.5	
Bhutan	4.7				0.0
2000		13.9	64.6	21.5	
2010		14.7	69.1	16.2	
India	297.3				7.0
2000		61.4	21.5	17.1	
2010		60.4	23.0	16.6	
The Maldives	0.03				0.6
2000		33.3	30.0	0	
2010		3.3	3.3	0	
Nepal	14.3				0.0
2000		29.5	33.7	36.8	
2010		29.4	25.4	45.2	
Sri Lanka	6.5				1.3
2000		37.5	36.4	26.1	
2010		42.1	28.8	29.1	
South Asia incl India	335.8				9.6
2000		59.2	22.5	18.2	
2010		58.5	23.4	18.1	
South Asia excl India	38.5				2.6
2000		42.5	30.4	27.0	
2010		43.9	26.5	29.6	

[a] Regional totals and figures on other land uses were calculated based on the available country figures. The other land uses include fields, pastures, and settlements.
[b] The 2010 agriculture figures are 2008 data.

India the lowest. In 2010, South Asia's total carbon stock in forest biomass was estimated at 3,762 million t, which was around 1.3% of the global total.

GHG Emissions and Climate Trends

GHG Emissions

In 1994, South Asia's total GHG emission including those from land-use change and forestry (LUCF) amounted to 1,425.6 million t CO_2e, of which India contributed 86%. Based on available data, the combined total GHG emission of Bhutan, India, and Sri

Table 11 **Forest Areas and Carbon Stock Biomass, South Asia**

	Bangladesh	Bhutan	India	The Maldives	Nepal	Sri Lanka	South Asia including India	South Asia excluding India
Total forest area ('000 ha)								
2000	1,468	3,141	65,390	1	3,900	2,082	75,982	10,592
2005	1,455	3,195	67,709	1	3,636	1,933	77,929	10,220
2010	1,442	3,249	68,434	1	3,636	1,860	78,622	10,188
Primary forest area ('000 ha)								
2000	436	413	15,701		548	197	17,295	1,594
2005	436	413	15,701		526	167	17,243	1,542
2010	436	413	15,701		526	167	17,243	1,542
Forest plantation area ('000 ha)								
2000	271	2	7,167		42	221	7,703	536
2005	278	2	9,486		43	195	10,004	518
2010	237	3	10,211		43	185	10,679	468
Carbon stock (million tons)								
2000	82	313	2,377		520	74	3,366	989
2005	82	324	2,615		485	66	3,572	957
2010	80	336	2,800		485	61	3,762	962
Carbon stock (ton/ha)								
2010	55	103	41		133	33	47	
Compounded Annual Growth Rates (%)[a]								
Total forest area								
2000–2005	(0.2)	0.3	0.7	0.0	(1.4)	(1.5)	0.5	
2005–2010	(0.2)	0.3	0.2	0.0	0.0	(0.8)	0.2	
Primary forest area								
2000–2005	0	0	0		(0.8)	(3.2)	(0.1)	
2005–2010	0	0	0		0.0	0.0	0.0	
Forest plantation area								
2000–2005	0.5	0.0	5.8		0.5	(2.5)	5.4	
2005–2010	(3.1)	8.5	1.5		0.0	(1.1)	1.3	

ha = hectare.

[a] ( ) denotes deforestation rate.

Source: FAO. 2010. *Global Forest Resources Assessment 2010. Main Report*. Rome. http://www.fao.org/forestry/fra/fra2010/en/

Table 12 **Total GHG Emissions in South Asia** (million tons CO_2e)

Total (Net) **National Emissions, including LUCF**	CO_2e Emissions*			
	1994	**Reference**	**2000**	**Reference**
Bhutan	(2.2)	RGoB NEC (2000)	(4.8)	RGoB NEC (2011)
Bangladesh	53.8	GPRB MoEF (2002)		
India	1,228.6	GoI MoEF (2004)	1,301.2	GoI MoEF (2012)
The Maldives	0.16	RoM MHHE (2001)		
Nepal	39.3	GoN MoPE (1994)		
Sri Lanka	106.1	DSRSL MoE (2000)	12.6	DSRSL MoE (2011)
Total South Asia	**1,425.6**		**1,309.0**	
Total of Bhutan, India, and Sri Lanka	1,332.4		1,309.0	

( ) = negative, CO_2e = carbon dioxide equivalent, LUCF = land-use change and forestry.

* The detailed GHG data from land use, land-use change, and forestry for 1994 and 2000 came from the countries' First and Second National Communications to the United Nations Framework Convention on Climate Change (UNFCCC). The 2000 data for Bangladesh, the Maldives, and Nepal were not available.

Lanka was 1,309.0 million t CO_2e in 2000, an apparent decrease (improvement) from the 1994 level of 1,332.4 million t CO_2e (Table 12).

Energy-using activities were a major source of GHG emissions in South Asia. These included specific activities in energy conversion, manufacturing, transportation, agriculture, residential, and commercial sectors. Based on available data from Bhutan, India, and Sri Lanka, energy-related emissions increased from 61.3% of their total emissions in 1994 to 79.4% in 2000, or a 27.1% increase between the two periods (Table 13). While GHG emissions from activities not using energy—in agriculture and waste production—increased between 1994 and 2000, those in land-use change and forestry declined by more than 700%, making the three countries a net sink for GHG emissions. Across Bhutan, India, and Sri Lanka, GHG emissions from all activities declined by 1.8% during 1994–2000.

Total GHG emissions of energy-using activities across South Asia increased by 98.2% during 1990–2005, while global emissions increased by only 30.8% (Table 14). Of the increases, Nepal had the highest (233.3%), and India the lowest (95.5%). The region's contribution to global GHG emissions from energy-using activities increased from 2.9% in 1990 to 3.7% in 1995 and 4.4% in 2005.

Historical and Projected Climate Trends

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, past and present climate trends and variability in all of Asia are generally characterized by increasing mean surface air temperature, although varying by country and season. In recent decades, the observed temperature increases in some parts of Asia have ranged from less than 1°C to 3°C per century (IPCC 2007). In terms of precipitation,

Table 13 **GHG Emission by Sector, South Asia, 1994 and 2000** (million tons CO_2e)

Sector	South Asia 1994	Bhutan, India, and Sri Lanka: 1994 as % South Asia	1994	2000	1994–2000 % Change	World 2000
Energy	835.8	97.8	817.2	1,038.8	27.1	26,890.4
Industrial process	104.6	98.6	103.1	89.3	(13.4)	1,369.4
Agriculture	405.2	86.4	349.9	361.3	3.3	5,729.3
Land-use change and forestry	54.6	70.7	38.6	(235.1)	(709.1)	7,618.6
Waste production	25.4	92.5	23.5	54.6	132.3	1,360.5
Total	1,425.6		1,332.4	1,309.0	(1.8)	43,058.2

( ) = negative, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Sources:
RGoB NEC (Royal Government of Bhutan, National Environment Commission). 2000. *Initial National Communication Under the United Nations Framework Convention on Climate Change (UNFCCC)*. November. Thimphu. http://unfccc.int/resource/docs/natc/bhunc1.pdf?bcsi_scan_9688b637a46568db=1&bcsi_scan_97e98328e2b67804=0&bcsi_scan_filename=bhunc1.pdf
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GoI MoEF (Government of India, Ministry of Environment and Forest). 2004. *India's Initial National Communication to the United Nations Framework Convention on Climate Change (UNFCCC)*. New Delhi.
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DSRSL MoE (Democratic Socialist Republic of Sri Lanka, Ministry of Environment). 2000. *Initial National Communication Under the United Nations Framework Convention on Climate Change (UNFCCC), Final Draft*. Colombo. http://unfccc.int/ttclear/pdf/TNA/Sri%20Lanka/SriLankaINC_finaldraft.pdf.
______. 2011. *Second National Communication on Climate Change to the UNFCCC*. Colombo.

Table 14 **GHG Emissions from Energy-Using Activities, South Asia** (million tons CO_2e)

	GHG Emissions: 1990	1995	2000	2005	% Change 1990–2005
Bhutan		0.09			
Bangladesh	13.6	20.5	25.2	36.3	166.9
India	586.9	779.6	968.4	1,147.5	95.5
The Maldives		0.13			
Nepal	0.9	1.74	3.1	3.0	233.3
Sri Lanka	3.74	5.5	10.8	12.3	228.9
South Asia	605.1	807.6	1,007.5	1,199.1	98.2
World	20,783.3	21,810.0	23,455.1	27,136.0	30.6
South Asia as % of the World	2.9	3.7	4.3	4.4	

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: IEA (International Energy Agency). 2007. *World Energy Outlook 2007, [the People's Republic of] China and India Insights*. OECD/IEA. Paris.

the region generally experienced prolonged dry spells and increased intensity of rainfall. Table 15 summarizes the historical and projected trends in surface air temperature and precipitation in the six South Asian countries covered in this study.

Studies on climate change in South Asia vary in their estimates of future temperature and precipitation due to differences in type of models used and scenarios considered. In general, however, warming is projected across the region; in IPCC's moderate scenario, already warm areas such as the Maldives and Sri Lanka are projected to have the lowest temperature rise of about 1°C and the higher altitude areas of Bhutan and Nepal to have a 1.5–2.5°C rise (Nakicenovic and Swart 2000, as cited in World Bank 2009). The projections on future precipitation suggest that the wet regions will get wetter, and the dry regions drier, with higher but more variable and intense rainfall expected across South Asia (except in western India, which could see even less rainfall) (World Bank 2009).

Using IPCC scenario A1F1 (that is, the highest future emissions trajectory), the average surface air temperature in South Asia is projected to increase by 1.17°C in the 2020s (from the baseline 1961–1990 level) during December to February, and by 0.54°C from June to August. The 2020s precipitation is estimated to decrease by 3% during December to February, and increase by 5% in June to August, against the 1961–1990 level.

Similarly, under IPCC scenario B1 (with the lowest future emission trajectory), average temperature is estimated to rise by 1.11°C and 0.55°C during December to February and June to August, respectively. Thus, projected warming in South Asia in the 2020s will appear to be more pronounced during winter than during summer. Precipitation in the 2020s is projected to increase, by 4% in December to February and by 7% during June to August. Regionally, most models project lower rainfall during winter, but with an increase in heavy rainfall events and a decrease in the annual number of rainy days, possibly by up to 15 days, over a large part of the region (IPCC 2007).

Emerging Impacts of Climate Change

The above projections indicate that climate variations in South Asia will be heterogeneous, with some regions experiencing more intense precipitation and increased flood risks, while others encounter sparser rainfall and prolonged droughts. The impacts will also vary across sectors, locations, and populations and affect most sectors, including water, energy, food security, biodiversity, human health, and coastal resources and communities (Sivakumar and Stefanski 2011).

Water Resources

Climate change will affect the water availability in South Asia due to changes in precipitation and run-off patterns. Rapid depletion of water resource is already a cause for concern in many countries in South Asia. It is estimated that about 2.5 billion people in the region will be affected by water stress and scarcity by 2050 (UNDP 2006).

As a result of global warming, the snow mass of the Himalayas has been decreasing at an accelerated rate. This can have serious adverse impacts as the Himalayas are lifelines to some 1.5 billion people living in the floodplains of its several rivers. The higher temperature is predicted to cause marked changes in seasonal rather than annual availability. The reduced water availability during the summer months may have serious impacts on

Table 15 **Historical and Projected Climate Trends in South Asia**

Country	Historical Climate Trends		Projected Changes in Climate Variables	
	Surface Air Temperature	Precipitation	Surface Air Temperature	Precipitation
Bangladesh	Generally increasing in the monsoon season (June to August); average monsoon season minimum and maximum temperatures have been increasing by 0.03°C and 0.05°C annually, respectively. Average winter (December to February) minimum temperature increasing by 0.016°C and maximum temperature decreasing by 0.001°C annually (Rahman and Alam 2003, as cited in GPRB MoEF 2005). During 1985–1998, surface air temperature increased by about 1°C in May and 0.5°C in November.	Decadal rain anomalies above long-term averages since the 1960s.	Using 11 GCMs under IPCC B2 scenario, a steady increase in temperature with little inter-model variance with increase higher in winter than in summer (Agrawal et al. 2003, as cited in GPRB MoEF 2005). Based on a GCM, average increase will be 1.3°C in 2030 and 2.6°C in 2070. In 2030, it will rise by 1.4°C in winter and 0.7°C in monsoon; in 2070, it will be 2.1°C and 1.7°C in winter and monsoon, respectively (Ahmed et al. 1999, as cited in GPRB MoEF 2005).	Again based on 11 GCMs under IPCC B2 scenario, precipitation is estimated to increase during summer monsoon and decrease in winter (Agrawal et al. 2003, as cited in GPRB MoEF 2005).
Bhutan	Both the mean summer and winter temperatures show a rising trend (RGoB NEC 2011), a warming trend of about 0.5°C in 1985–2002, mainly in the non-monsoon seasons.	No detectable trend observed during 2000–2009 (RGoB NEC 2011); largely random fluctuations with no detectable systematic change on either annual or monthly scale (Tse-ring 2003, as cited in ICIMOD 2010).	Based on ECHAM5/A1B and HadCM3Q0/A1B scenarios, increase during 2010–2039 is estimated at 0.8°C and 1°C, respectively; in 2040–2069, increase will be 2°C and 2.4°C in the same respective scenarios (RGoB NEC 2011).	Based on ECHAM5/A1B and HadCM3Q0/A1B scenarios, mean annual precipitation will increase by 6% in 2010–2039, with a slight decrease (2%) in winter and a 4%–8% increase in the monsoon season (RGoB NEC 2011). Similarly, a moderate increase in mean annual rainfall in 2040–2069, with increase higher in monsoon than in winter.
India	Annual mean temperature increased at 0.56°C per century in 1901–2007 (GoI MoEF 2012), with accelerated warming observed in 1971–2007, and more so in 1998–2007. Warming more pronounced during pre-monsoon and monsoon seasons. In 1901–2007, minimum and maximum temperatures increased by 0.12°C and 1.02°C per century, respectively.	All-India monsoon rain shows no significant trend when averaged over 1871–2009, but shows a slight negative trend of 0.4 mm/year and an increase in extreme rainfall in many places (GoI MoEF 2012).	Analysis using the PRECIS model for the A1B scenario for the 2000s (2011–2040), 2050s (2041–2070), and 2080s (2071–2098) indicates an all-round warming. The estimated annual mean increase by the end of the century ranges from 3.5°C to 4.3°C (GoI MoEF 2012).	Analysis using the PRECIS model for the A1B scenario for the 2020s, 2050s and 2080s show no significant decrease in monsoon rainfall, except in some parts of the country (GoI MoEF 2012).

continued on next page

Table 15 *continued*

Country	Historical Climate Trends		Projected Changes in Climate Variables	
	Surface Air Temperature	Precipitation	Surface Air Temperature	Precipitation
The Maldives	Annual sea surface temperatures in Malé and Gan islands increased by about 0.2°C and 1.1°C–1.6°C, respectively, per decade. Sea surface temperature and mean tide level at Hulhulé weather station (which provide a general indication of current climate risks for the country) have consistently increased during all seasons (World Bank 2009).	No significant long-term trends were observed in daily, monthly, or annual rainfall patterns during 1989–2005 (World Bank 2009).	By 2025, the maximum temperature of 33.5°C—currently a once-in-20-year event—will become a once-in-3-year event. By 2100, the annual maximum temperature is projected to increase by around 1.5°C (World Bank 2009).	Extreme daily rainfall (of 180 mm) and extreme 3-hour rainfall (of 100 mm) are expected to occur twice as often in the same time frame (currently 100 years and 25 years, respectively) by 2050 (World Bank 2009).
Nepal	Annual temperature will increase by 0.09°C in the Himalayas and by 0.04°C in the Terai, with the temperature rise higher during winter (IPCC 2007). Another study reported the country's mean temperature as steadily increasing by 0.04°C per year during 1997–2005. Rate of temperature increase was lower in lower altitudes and higher in higher altitudes (GCISC et al. 2005).	Total number of rainy days will increase, while the number of days with more intense precipitation is increasing (GoN WECS 2011).	Based on a 13-GCM ensemble under A2 scenario, estimates show an overall annual increase by 1.24±0.20°C in the 2020s, with estimates relatively larger in winter than in summer (GCISC et al. 2005).	Based on a 13-GCM ensemble under A2 scenario, estimates for the 2020s show an increase in precipitation for the monsoon season and a decrease during winter (GCISC et al. 2005).
Sri Lanka	Annual maximum and minimum temperatures showed increasing trends by up to 0.046°C and 0.0269°C per year, respectively, during 1961– 2000 (DSRSL MoE 2011). Average temperature across the country increased by 0.016°C per year during 1961–1990 (IPCC 2007).	Annual mean rainfall decreasing by 9.46 mm per year during 1961–2000, with considerable variation across districts, and also in intensity, and temporal and spatial distribution. The number of rainy days appears to be decreasing with prolonged dry spells and increased intensity of rainfall (DSRSL MoE 2011).	Using GCMs HadCM3, CSIRO, and CGM, mean increase in summer 2100 under scenarios A1F1, A2, and B1 is estimated to be 2.4°C, 2°C, and 1.1°C, respectively (DSRSL MoE 2011).	Under a moderate IPCC emission scenario A2, one model shows an increase in annual rainfall up to 400 mm by 2100; another model shows an increase up to 133 mm; a third model shows a decrease to 161 mm by 2100. These show seasonal variations, with the southwest monsoon period showing increases in areas already receiving high rainfall. However, the northwest monsoon period show less noticeable changes (DSRSL MoE 2011).

CSIRO = Commonwealth Scientific and Industrial Research Organisation, GCM = general circulation model, IPCC = Intergovernmental Panel on Climate Change.

Note: ECHAM5/A1B and HadCM3Q0/A1B are types of GCM.

irrigation and hydropower, especially in downstream countries like Bangladesh, where 92% or more of the country's annual run-off is dependent on the transboundary rivers (GPRB MoEF 2005). In the short term, the rise in temperatures will increase glacier melting and increase river flow. However, the contribution of glacier melt to run-off will gradually decrease over the next few decades (IPCC 2007; Sharma et al. 2009).

Recent observations have estimated the maximum rate of glacier retreat at about 41 meters per year (m/yr) in the Indian Himalayas, 74 m/yr in Nepal, and 160 m/yr in Bhutan (Bajracharya et al. 2007). Assessments of the global warming climate models estimate the glacier retreat in debris-covered glaciers for 2010–2039 to be 78.2–168.0 m/yr. For debris-free glaciers, the retreat rates for 2040–2069 are estimated to be 20.1–43.2 m/yr. This implies more frequent glacial lake outburst flood (GLOF) events by 2010–2039 and even more so in 2040–2069 (RGoB NEC 2011).

River Run-off

Climate change is likely to affect the annual variability in river flow pattern, which is attributed more to changes in precipitation than to temperature changes (IPCC 2001). In the snow-fed rivers, as the peak melting season coincides with summer monsoon season, accelerated snow and glacier melting combined with an increased precipitation will result in increased river run-off and a likely occurrence of floods in the Brahmaputra and Koshi basins which could be as high as 20%–40% above the baseline (Gosain, Shrestha and Rao 2010).

With increased melting of snow and glaciers, the region will initially have increased river run-off in the lean season. But with the decrease of snow mass, which acts as a source of water in the rivers during the lean season, water availability will be reduced substantially in the long term, affecting the livelihood and energy systems in the downstream countries. Precipitation variability affects the run-off patterns of the rainfed rivers. In India, climate change is likely to adversely affect irrigated agriculture and installed power capacity due to reduced flows in the dry season and higher flows in the wet season, which will also cause severe droughts and flood problems in both urban and rural areas (GoI MoEF 2012).

In India, assessments based on the PRECIS regional climate model with projected climate change under IPCC A1B scenario show an increase in the precipitation at the basin level in the majority of the river systems except in Brahmaputra, Cauvery, and Pennar in the near term (2021–2050). However, in the longer term (2071–2098), all river systems are found to exhibit an increase in precipitation. Many of these basins are, however, very big and have considerable spatial variability (GoI MoEF 2012).

In Bhutan, reports of dwindling water sources are increasing and climate change may render the country much more vulnerable even though it has not experienced severe water shortages in the past. However, climate impact assessments under A1B scenario (based on ECHAM5 and HadCM3Q0 models) estimate no major negative impacts of climate change on water coverage in the country during 2010–2039 and 2040–2069 (RGoB NEC 2011).

Glacial Lake Flood Outburst. The increased glacial melt in the Himalayas is resulting in the formation and continuing growth of glacial lakes; this is likely to result in increased frequency and intensity of extreme events like flooding or GLOF events. GLOFs adversely affect the downstream livelihood and energy infrastructures. According to ICIMOD (2010), 24 lakes in Bhutan and 21 lakes in Nepal are recognized as potentially unstable, posing the risk of outburst floods to outlying communities. Several GLOF events have been reported in the past in the northern region with some having transboundary impacts, like the Dig Tsho Lake outburst at Bhote Kosi River basin in Nepal in 1985 and the 140-m deep Luggye Tsho outburst in Bhutan, which released 10 million m^3 of flood water in 1994.

Floods and Droughts. Many parts of Asia are already experiencing increasing frequency and intensity of droughts, particularly during the summer and normally drier months, attributed largely to a rise in temperature. The northern regions of India, Nepal, and Bangladesh have seen serious and recurrent floods during 2002–2004 (IPCC 2007). In India, extreme events like floods and droughts have become a common feature. It is estimated that 40 million ha of its land area (i.e., 12% of the total area of the country) is flood prone, while 51 million ha (i.e., 16% of the total area) is drought prone (GoI MoEF 2012).

Impacts on Hydropower

One of the major impacts of changes in level and seasonal pattern of precipitation, run-off, and extreme events like GLOF is on hydropower generation capacity and electricity generation from hydropower plants in different seasons. According to Chaulagain (2006), the glaciers in the Nepalese Himalayas have been retreating so fast in recent decades that hydropower potential is likely to decrease by 6% even without any further warming. However, hydropower generation may benefit or suffer depending on the run-off variability and the reservoir type (storage or run-of-river type) of the project. Landslides and floods would result in increased siltation in river flows, which would lower reservoir capacity and damage mechanical equipment.

In Bhutan, a study using two climate scenarios (A2 and B1), taking into account glacial mass balance, snow storage, subsurface water storage, and stream flow between 1981–2010 and 2021–2050, estimated the change in mean annual discharge available for hydropower production to vary between 13% decrease and 7% increase for all catchments and both A2 and B1 scenarios. The mean annual discharge available for hydropower production in the longer term, from 1981–2010 to 2071–2100, will be affected by the reduced contribution of glacier ice melt to stream flow (Beldring 2011).

Groundwater

The Maldives mainly depends on groundwater and rainwater as a source of freshwater. Both are highly vulnerable to changes in the climate and sea level rise. The projected sea level rise is likely to force saltwater into low-lying freshwater resources. Even though the groundwater is recharged through rainfall and rainfall is predicted to increase under climate change, the spatial and temporal distribution in rainfall pattern is not clear (Ministry of Environment and Construction 2005, as cited in Sivakumar and Stefanski 2011).

Sea Level Rise and Coastal/Marine Resources

The region’s long and densely settled coastlines are highly vulnerable to sea level rise and occurrence of extreme sea level-related events. The coastal areas are expected to incur coastal inundation and erosion, displacement of communities, increased coastal management and defense costs, and potential for more intense tropical cyclones. Poor people in the low-lying river deltas of Bangladesh, India, the Maldives, and Sri Lanka are at the highest risk.

The very survival of the Maldives is in jeopardy, as the average height of its islands is 1.5 meters above mean sea level, and its highest point is less than 2 meters above sea level. A large proportion of Sri Lanka's coastal land is less than 1 meter above sea level and could be submerged with rising water, along with critical transport infrastructure.

According to IPCC (2007), the current rate of sea level rise in the coastal areas of Asia is 1–3 millimeters (mm) per year which is above the average global sea level rise in the second half of the 20th century (1.8 ± 0.3 mm per year). During the early 21st century, sea level rise in the order of 2–3 mm per year as a result of climate change has been estimated.

In Bangladesh, sea level is predicted to rise 45 centimeters (cm) by 2050, affecting 10%–15% of the land area and an estimated 35 million people (ADB 2010c). In India, sea level is projected to rise by around 15–38 cm, placing major cities like Kochi, Kolkata, and Mumbai at risk.

Sea level rise threatens drinking water supply, agriculture, and aquaculture by allowing saline water intrusion. In Bangladesh, more than 100 million ha of arable land are affected. All of the Maldives is affected by saline water intrusion due to rising sea level. Coastal areas of Sri Lanka face similar concerns.

Coastal ecosystems across the region are all vulnerable to the impacts of sea level rise due to the bleaching of coral reefs, which could kill the corals and lead to decline in reef-dependent species, distorting the dynamics of the ecosystems (World Bank 2009).

In Bangladesh, cyclones and storms are estimated to become more intense with climate change with devastating effects on human life (GPRB MoEF 2005). Cyclones originating from the Bay of Bengal have been decreasing since 1970. However, their intensity has increased (Lal 2001, cited in IPCC 2007), causing severe floods and significant damage to habitation near the coastal areas. The country is likely to face the problem of increased flooding resulting from climate change as both coastal (from sea- and river water) and inland flooding (from rivers/rain water) are expected to increase (GPRB MoEF 2005). In India, the eastern coast is particularly vulnerable to storm surges generated by tropical cyclones in the Bay of Bengal. Simulations using the PRECIS climate model indicate that the 100-year return level for the occurrence of cyclones will increase by about 15%–20% in 2071–2100 compared to the 1961–1990 baseline in all the stations north of Visahkhapatnam. However, the increment is estimated to be less than 5% in another two cities in the east coast, Sagar and Kolkata (GoI MoEF 2012).

Agriculture

Temperature rise will lower rice and wheat yields in tropical parts of South Asia; these crops are already being grown close to their temperature tolerance threshold in the region (Kelkar and Bhadwal 2007, as cited in Sivakumar and Stefanski 2011). Elsewhere, for example in Nepal, a 4ºC rise in temperature and 20% increase in precipitation could result in an increase in the marginal yield of rice from 0.09% to 7.5%. Beyond those temperature and precipitation increases, the yield would decline. In the case of wheat, yield was observed to increase with rise in temperature in the western region of Nepal, while it declined in other regions of the country (GoN MoPE 2004).

Additionally, more frequent and extreme events, such as droughts and floods, are expected to make local crop production even more difficult. It is expected that crop yields could decline by up to 30% in South Asia by mid-21st century (IFAD undated).

With the immense geographical diversity in India, the projected impacts of climate change on crop yields are expected to exhibit variations across different regions of the country. In arid regions, where crops already suffer heat stress, a small increase in temperature could lead to a dramatic decline in their yields. However, it could result in an increase in yields in the cooler Himalayas (World Bank 2009). The food and nutrition security of India currently depends, to a great extent, on the production of wheat and rice, which together accounted for 78% of the total food grain production in 2009/10. The food supply situation will become more challenging as demand grows over time; for example, it is estimated to increase by 30%–50% by 2020 (GoI MoEF 2012).

Field experiments with elevated atmospheric carbon dioxide levels, to 550 parts per million (ppm) under controlled environment conditions, have improved yields of wheat, chick pea, green gram, pigeon pea, soybean, tomato, and potato, by 14%–27% (GoI MoEF 2012). Similarly, crops like rice, tea, and coconut in Sri Lanka studied under controlled conditions showed positive response to carbon dioxide elevation (DSRSL MoE 2011).

Crop modeling studies for projected climate changes up to 2100 show Sri Lanka's tea industry to be also vulnerable to climate change. The yield of high elevation tea is expected to improve while that of the mid- and low-elevation plantations is expected to decline (DSRSL MoE 2011).

In Bhutan, the agriculture sector is facing loss of crops due to unusual outbreaks of pests and diseases, erratic rainfalls, windstorms, droughts, and flash floods/landslides that are increasing annually. But different climate models give conflicting projections on the future impacts of climate change on crops there. An assessment (based on HadCM3Q0) under the IPCC A1B scenario showed rice yield to decrease slightly during 2010–2039 but increase dramatically during 2040–2069. Another assessment (based on ECHAM5/A1B) shows rice yields would decrease in both periods. Similarly, maize yield is expected to decrease in both the future periods according to an assessment based on HadCM3Q0, while an assessment based on ECHAM5 projects that yields would decrease in 2010–2039 but increase in 2040–2069 (RGoB NEC 2011).

In Bangladesh, climate change is projected to increase the intensity and frequency of natural disasters and to cause changes in agricultural yields, with potentially severe implications for rural poverty (World Bank 2009).

Forests

There are few studies on impacts of climate change on forests in South Asia, mostly focused on India. An assessment under IPCC scenarios A2 and B2 shows that of the forested grids in India, 39% are likely to undergo shifts in forest type under A2 scenario and 34% under B2 scenario by the end of this century (Chaturvedi et al. 2011).The assessment estimates the net primary product of the forests to increase by 68.8% under A2 scenario and 51.2% under B2 scenario. Similarly, soil organic carbon is projected to increase by 37.5% under A2 and 30.2% under B2 scenario. The same study finds that about 39% of the forested grids in India are vulnerable to projected climate change, with forests in upper Himalayas and parts of central India being among the most vulnerable. A study by Ravindranath et al. (2006) indicates a shift under A2 and B2 scenarios toward wetter forests types in the northeastern region and drier forest types in the northwestern region.

Another assessment, using the Integrated Biosphere Simulator for the A1B scenario, indicates an expansion of tropical evergreen forests in the eastern India plateau and in the Western Ghats; almost no change in the vegetation type in the northeast of the country; and a slight expansion of forests into the western part of central India. Further, the net primary product would increase over India in the A1B scenario, by an average of 30.3% by 2035, and by 56.2% by 2085 (GoI MoEF 2012).

In Nepal, increased incidence of forest fires will likely occur and affect the availability of already scarce fuelwood sources in the future (GoN MoEnv 2010). In Bhutan, assessments based on two climate models (HadCM3Q0 and ECHAM5), coupled with the Holdridge Forest Classification System, show a general northward migration of the major forest classes of the country in the future under the A1B scenario, with subtropical species invading the southern margins and alpine species decreasing on the northern margins of the country (RGoB NEC 2011).

Human Health

In South Asia, human health is affected by changes in the frequency and intensity of temperature extremes and severity of weather events, such as heat waves, flooding, and increased intensity of tropical cyclones and storm surges (World Bank 2009). The direct health impact can be heat stroke, while indirect impacts include diarrheal or other water-related diseases from water contamination via flooding; higher risk of mortality from the impact of large-scale loss of livelihoods due to extreme events; and deterioration in nutritional health arising from crop failure caused by droughts and especially from high night temperatures.

Changes in climate may alter the distribution of important vector species (for example, mosquitoes). Malaria is already one of the most important vector-borne diseases in Bangladesh, India, and Sri Lanka. In Nepal too, many of the common diseases such as malaria, Japanese encephalitis, and *kala-azar* (a chronic parasitic disease of internal organs) may spread to new regions as an adverse impact of climate change (Regmi and Adhikari 2008). Changes in temperature and precipitation patterns have the potential to expand the geographic range of malaria into temperate and arid parts of South Asia (Hales et al. 2003, as cited in World Bank 2009).

In Bhutan, according to HadCM3Q0 and ECHAM5 modeling, there would be slight increase or no change in the number of cases of cholera and PFM (malaria), and moderate to significant increases in the incidence of diarrhea, dysentery, other kinds of malaria, and typhoid for both Thimphu and Phuntsholing regions. The ECHAM5 model for dengue shows a moderate increase in incidence across the whole of Bhutan during 2010–2039 and a significant increase in 2040–2069, while the HadCM3Q0 model projects a significant decrease in dengue incidence (RGoB NEC 2011).

3 Methodology

This chapter describes the approaches applied to assess clean technologies and resource options during 2005–2030 for economic activities/sectors using energy and those not using energy, in Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka. In the case of India, discussions related to energy-using activities are based on results generated by the TERI-MoEF model (also based on the MARKAL framework) (GoI MoEF 2009), which was presented at the Climate Modeling Forum (2009). The chapter also discusses the methodology used to assess the incremental costs and GHG abatement potential associated with applying clean technology and resource options in place of the conventional ones.[9]

Assessing Technology and Resource Options for Energy-Using Activities

The assessment of technology and resource options for energy-using economic activities used an energy system optimization model based on the MARKet ALlocation (MARKAL) framework that determines the cost-effective set of technologies and energy resources to meet projected demand for services in different sectors in future years (Figure 1); and models to project the levels of service demands in future years.

Energy System Model

This study used country-specific energy system models based on the MARKAL framework to determine least-cost technology and energy resource options to meet the projected service demands and associated costs and estimate GHG emissions during 2005–2030 in the five countries. The model is a multi-period, bottom-up, dynamic optimization model primarily driven by projected demands for services. It considers feasible alternative paths of a reference energy system[10] (Figure 2) for the flow of an energy resource from its supply

9 Since this study was completed, a report by the World Bank (International Bank for Reconstruction and Development/The World Bank 2012) has evaluated and compared the enabling environment for private sector investment in clean energy technologies in several South Asian countries. The report also provides a Climate Investment Readiness Index that scores and compares the countries in terms of technical, financial, market, and regulatory barriers and incentives to private sector investment.

10 The reference energy system (RES) is a network representation of all of the technical activities required to supply various forms of energy to end-use activities—extraction, refinement, conversion, transport, distribution, and utilization. Each of these activities is represented by a link in the network for which efficiency, environmental impact, and cost coefficients may be specified. The network is quantified for a given year with the level of energy demands and the energy flows through the supply activities that are required to serve those demands (http://adsabs.harvard.edu/abs/1976STIN...7717574B).

source to points of end use and passing through the intermediate stages of energy conversion and transmission, as may be necessary.

The energy system model computes energy balances at all levels of the RES (i.e., primary energy sources, energy conversion, transmission and processing technologies, and end-use energy-using services) and finds the set of technology options and energy commodity or fuel type that minimize the total discounted system cost of meeting service demands over the entire planning horizon. The total system cost includes the annualized investment cost of technologies; fixed and variable operation and maintenance costs; cost of imported energy and materials; cost of domestic energy resource production; fuel and material delivery costs; and taxes and subsidies associated with energy sources, technologies, and emissions (Loulou, Goldstein, and Noble 2004). The model consists of four modules: primary energy supply, conversion and process technology, end-use service energy demand, and environmental emissions. The end-use service demand module covers five economic sectors—agriculture, commercial, industrial, residential, and transport. These sectors are further subdivided into end-use services, the demands for which have to be provided as an input to the model. Estimation of GHG emissions consisting of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are dealt with in the environmental emissions module.

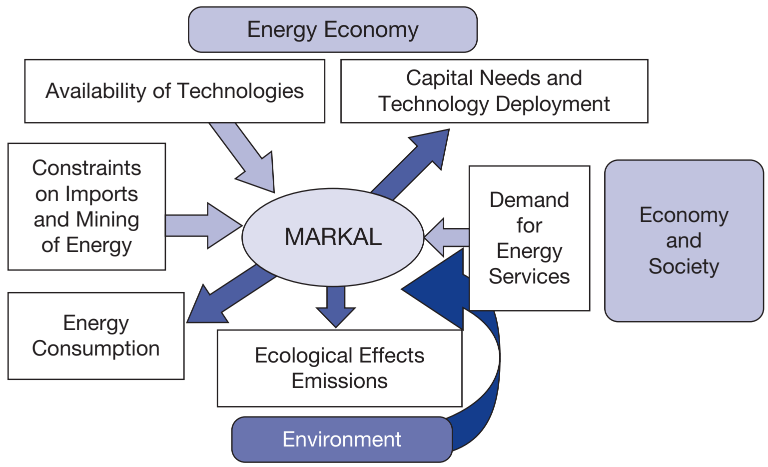
The energy system model is driven by the demands for energy-using services (e.g., lighting, cooking, space heating, space cooling, and passenger and freight transport services) rather than the demands for different kinds of energy commodities or sources per se in different sectors of the economy. For example, the model uses the demand for passenger transport services (e.g., passenger-kilometers of the services) and freight transport services (e.g., ton-kilometers of services) instead of estimating directly the demand for transport fuels (e.g., gasoline and diesel) as a driving force in the transport sector. This allows the energy system model to consider alternative technology and fuel options that could be used to meet future transport service demands. Similarly, in the case of cooking, the model normally uses as a data input the projected demand for useful energy needed for cooking instead of the amounts of individual fuels. This would allow the model to consider alternative cooking technologies and fuels (e.g., stoves using improved or conventional biomass, biogas, liquefied petroleum gas [LPG], kerosene, electricity, etc.) to meet the demand for cooking.

The model is required to satisfy a number of constraints in order to properly characterize the associated energy supply and use system in the economy. Key constraints in the energy system model include the conditions that need to be satisfied in relation to energy-using service demands, level of technology penetration, energy conversion and transmission capacity, electricity and heat balance, peaking reserve constraint, base load, seasonal availability factors, and emission constraints.

Data Requirements

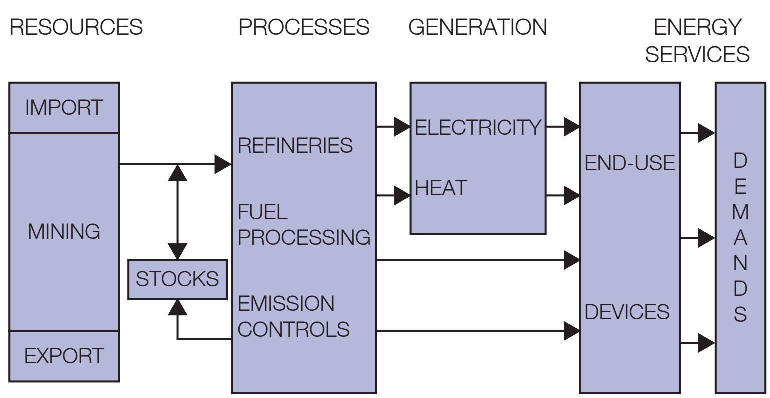
The development of a MARKAL-based energy system model requires data that include (i) costs of energy resources/energy extraction and delivery, price of imported fuels, costs of energy conversion-, transmission- and utilizing-devices, fixed and variable operation and maintenance costs; (ii) technology characteristics (size or capacity of devices, fuels, in/out efficiency, technology availability year, lifespan of devices, etc.); (iii) size of energy

Figure 1 **Overview of the MARKAL Framework**



Source: Zonooz, M.R.F., Z.M. Nopiah, A.M. Yusof, and K. Sopian. 2009. A Review of MARKAL Energy Modeling. *European Journal of Scientific Research.* 26(3): 352–361.

Figure 2 **A Reference Energy System**



Source: Seebregts, Ad J., G.A. Goldstein, and K. Smekens. Undated. *Energy-Environmental Modeling with the MARKAL Family of Models*. Energy Research Center of the Netherlands (ECN). International Resources Group Ltd.

resources available; (iv) projected values of service demand for each end-use category; (v) environmental emission factors; and (vi) other data, such as discount rate, seasonal/ day-night fractions, electric reserve margin, start year, and time horizon.

National Service Demand Projection

The demands for the various end-use services are estimated separately. In the residential sector, end-use services considered include lighting, cooking, water heating, space heating, space cooling, agro-processing and animal feed preparation,[11] and other services using electrical appliances. The commercial sector is disaggregated into education, health, hotel and restaurant, and other subsectors; end-use service demands are lighting, space heating, space cooling (air conditioning), water heating, and other electrical appliances. The transport sector is disaggregated into road-, air-, rail-, and water-based mass transport systems; service demands are disaggregated into freight and passenger transport services. The industry sector is disaggregated into cement, brick, iron and steel, sugar, and pulp and paper subsectors, with the remaining manufacturing activities grouped as "other industries."

For each country, end-use service demands for the base year 2005 are estimated using available information on sector energy consumption, national energy balance, and end-use service demand technologies in different sectors. The following sections briefly describe the approaches used to estimate end-use service demands for 2005–2030. The approaches applied differed depending on the data available in each country.[12]

The respective future demands for end-use services in the agriculture, commercial, and industry sectors are estimated considering that the service demand is characterized by a constant elasticity demand function of the corresponding sector value added as given by

$$SD_t = SD_o \times \left(\frac{VA_t}{VA_o} \right)^{\delta}$$

where SD_t and SD_0 represent service demand in year t and year 0 (base year), respectively; and VA_t and VA_0 denote the sector value added in year t and base year also, respectively. In the absence of data, this study assumed that the value added elasticity of service demand (δ) was unity.

The total demand for each end-use service in the residential sector is estimated using a Cobb-Douglas demand function of population (alternatively, total number of households) and total income, represented by GDP. In the absence of the time-series data on service demand, the demand for the end-use service in a future year is estimated by

$$SD_t = SD_o \times \left(\frac{POP_t}{POP_o} \right)^{\alpha} \times \left(\frac{I_t}{I_o} \right)^{\beta}$$

where POP_t and POP_0 are the total population in year t and base year, and I_t and I_0 are the year t and base year GDP, respectively, and α and β are the population and GDP elasticities of service demand, respectively. Unitary values of elasticities α and β are assumed in the absence of data that will allow estimating them econometrically. In addition, the population in areas using electric lighting was distinguished from the population in areas without electric lighting (e.g., kerosene-based lighting) in the course of estimating the demand for lighting in the residential sector.

[11] Agro-processing and animal feed preparation in Nepal and Bhutan are included under the residential sector.
[12] The details of the country-specific approaches are discussed in the individual country reports.

Demand for passenger transport services in year t (PTS_t) is projected by

$$PTS_t = PTS_o \times \left(\frac{POP_t}{POP_o}\right)^{\eta} \times \left(\frac{GDP_t}{GDP_o}\right)^{\mu}$$

where PTS_0 is the passenger transport service demand in the base year; and GDP_t and GDP_0 denote GDP in year t and base year, respectively, and η and μ represent population and GDP elasticities of passenger transport service demand, respectively. Except for those in Sri Lanka, the population and GDP elasticities (η and μ) of passenger transport service demand were assumed to be unity due to lack of data to estimate them econometrically.[13] The PTS_0 is estimated as

$$PTS_{\hat{O}} = \sum VS_{i,o} \times AAKM_{i,o} \times OC_{i,o}$$

where $VS_{i,0}$ denotes the stock of vehicle type i in the base year, while $AAKM_{i,0}$ and $OC_{i,0}$ are the base year annual average distance in kilometers traveled by, and occupancy rate of, vehicle type i, respectively.

The demand for freight transport service in year t (FTS_t) has been estimated as

$$FTS_t = FTS_o \times \left(\frac{VA_t}{VA_o}\right)^{\theta}$$

where FTS_0 is the base year freight transport service demand and VA_t and VA_0 are the respective transport sector value added in years t and 0 and θ is the value added elasticity of freight transport service demand. Again due to lack of the required time-series data and except in Sri Lanka, the value added elasticity (θ) of freight service demand is assumed to be unity.

Assessing Technology and Resource Options for Activities Not Using Energy

The future levels of activities not using energy or "non-energy-using activities" in (sub) sectors like forestry, agriculture, land-use change, waste production, and industrial processes in the baseline (or business as usual) case were projected by assuming that the activity levels in the base year (2005) will grow at their historical average annual growth rates. Limits on the growth of the activity levels associated with resource constraints (e.g., limited land available for rice cultivation) are considered in so doing.

Unlike the case of activities using energy, a Microsoft Excel-based spreadsheet model following the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997) was used to estimate GHG emission from activities not using energy.

13 Econometric passenger and freight service-demand models were estimated and used for demand projections in the case of Sri Lanka. These are discussed in detail in the Sri Lanka country report.

Projected activity levels in each sector and corresponding emission factors were used to derive the emission estimates for future years. The emission factors were based either on the revised 1996 IPCC guidelines or on the country's First National Communication to the United Nations Framework Convention on Climate Change (UNFCCC).

In the GHG mitigation scenario, the first step in the analysis involves identifying, based on literature review and expert opinion, cleaner options to replace the conventional technologies and practices for each of the non-energy-using activities. Targets are then set to replace the level of usage of conventional options with the cleaner ones in future years to 2030. The corresponding annual GHG emissions with the adoption of the cleaner options are estimated considering the future activity levels, target level of cleaner options considered, and appropriate emission factors for the cleaner and the conventional options.

GHG Abatement Cost Analysis

Abatement Cost Analysis for Activities Using Energy

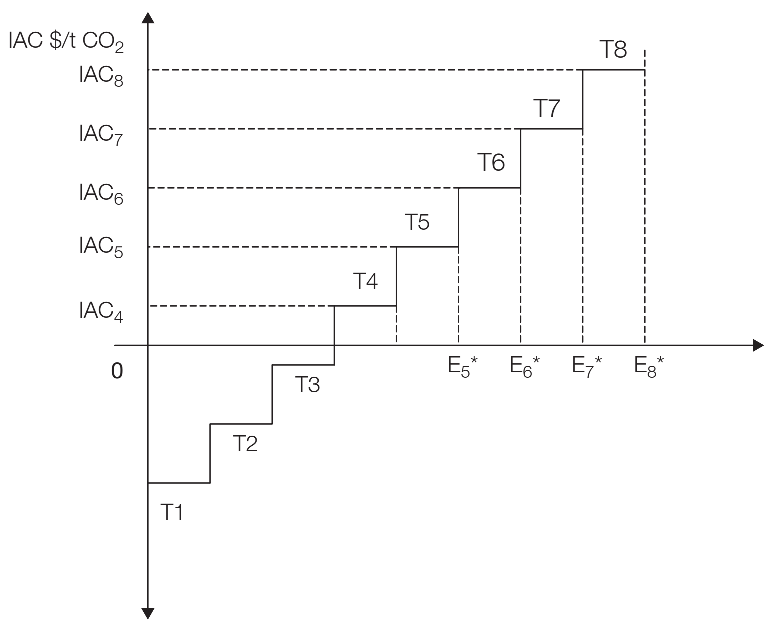
A GHG abatement cost curve provides information on the mitigation potential of individual clean technology options and the corresponding incremental abatement cost (IAC). The GHG abatement cost curve is derived from the following steps:

1. Identify the set of conventional technologies in a selected year in the base case that could be replaced with clean technologies.
2. Replace the sector-specific conventional technology with a more efficient or cleaner option.
3. Apply the MARKAL-based energy system model to estimate the changes in the total system cost and GHG emission with the adoption of the cleaner technology option.
4. Repeat steps 2 and 3 for all conventional technologies identified in step 1, to generate (i) preliminary values of IAC and GHG mitigation (emission reduction) potential for each cleaner option considered, and (ii) an initial ranking of cleaner technology options based on their abatement costs.
5. The cleaner options with the first and second lowest IACs are considered together to replace the corresponding conventional technologies, and the GHG emissions and total cost (with the adoption of the two cleaner options) are calculated using the energy system model.
6. Options with the three lowest IACs (based on the initial ranking in step 4) are considered together, and the values of IAC and GHG mitigation potential are recalculated for the option ranking third initially.
7. Repeat the process until all the identified cleaner options are adopted together, and the IAC and GHG mitigation potential of each option is recalculated. A new ranking of cleaner options is established based on their recalculated IAC values.

8. Repeat the whole process until the ranking of options between two consecutive iterations becomes the same; these are the final values of IAC and GHG mitigation potential.

The incremental abatement cost curve (IACC) is derived using the final values of the IAC and GHG mitigation potential of the cleaner options considered, which are presented in increasing order of their IACs. Figure 3 illustrates a typical IACC, where the width of a block in the horizontal axis is the GHG mitigation (emission reduction) potential of the corresponding option, and the height of the block (vertical axis) shows the option's IAC. For example, in Figure 3, technology option 1 (T1) has the lowest IAC, while technology option 8 (T8) has the highest IAC. The GHG abatement potential of option T8 is given by E_8^*-E_7^* (the horizontal width of the T8 block), while the option's IAC is given by block height IAC_8.

Figure 3 **GHG Abatement Cost Curve: An Illustration**



CO_2 = carbon dioxide, GHG = greenhouse gas, IAC = incremental abatement cost.
Source: Authors.

Abatement Cost Analysis for Activities Not Using Energy

Similar to that for energy-using activities, the first step in the analysis involves identifying cleaner options to replace the conventional options in the activities not using energy. A target is then set to replace a conventional option with a cleaner one in the selected year. The respective reductions in GHG emissions and annuitized values of the incremental costs associated with adopting the cleaner options are estimated. The incremental abatement cost of a cleaner option in the selected year is then obtained by dividing the annuitized value of the incremental abatement cost by the estimated level of GHG mitigation (emission reduction) in that year.

Unlike in the case of energy-using activities, the approach used here is not based on identification of options that minimize total cost of non-energy-using activities as a whole. Rather, the approach calculates the abatement cost associated with the replacement of a conventional option employed in a non-energy-using activity with a preselected cleaner option.

Scenarios Used in the Study

Two scenarios are considered in this analysis: a base case (also called "base"), and a scenario with carbon-tax profile for achieving the global GHG concentration stabilization target of 550 parts per million by volume (ppmv) of CO_2e (also called the "carbon-tax scenario").

Base Case

The base case considers energy system development without any climate policy interventions during 2005–2030. The market penetration level of the cleaner technology options for meeting the demand for an end-use service has been set to not exceed 50% of total service demand in 2030, while that of the conventional (less efficient) technologies is assumed to gradually decrease to 50% of the 2005 total service demand level. This assumption is necessary to make the analysis more realistic with the real world phenomenon of phasing out of the old technologies, and newer and efficient technologies replacing them. For example, if the share of fuelwood cooking stoves in the total residential cooking service demand is 12% in 2005, then the corresponding figure in 2030 would be constrained to not fall below 6%.

Table 16 summarizes the national data inputs used in this study. For the Maldives, the study used the medium growth rate scenario of projected population for 2005–2030. For Nepal, the 2001–2021 population growth rates projected by GoN CBS (2003) for the districts (i.e., mountain, hills, Terai, and Kathmandu Valley) were used in this study to project the population by physiographic region[14] for 2005–2020. Nepal's total population is projected to grow at a declining rate until 2021 (GoN CBS 2003), which is assumed in this study to continue during 2025–2030.

The total population of South Asia is estimated to increase by 40% during 2005–2030, or by 1.2% per year. In each of the six countries, the proportion of urban population is projected to increase, and that of rural population to decrease, in the same period. Regionally, the rural population is estimated to decline from 71% of the total population in 2005 to 60% in 2030, while the urban population is projected to increase from 29% in 2005 to 40% in 2030.

[14] Nepal is divided into five major physiographic regions, which run in more or less parallel bands from northwest to southeast. Each region has a distinctive agricultural and forestry land-use pattern. These regions are known as Terai, Siwaliks, Middle Mountains, High Mountains, and High Himal, from south to north direction (http://www.rrcap.unep.org/lc/cd/html/countryrep/nepal/intro.html).

Table 16 **Data Inputs**

	Bangladesh	Bhutan	India	The Maldives	Nepal	Sri Lanka
Discount rate (%)	10	12	15 (GoI MoEF 2009)	13	10	10
GDP growth rates (%) in 2005–2030						
Reference	BPDB (2006)	RGoB NSB (2005a; 2005b)	TERI (2006)[a]	RoM MMA (2000; 2010)	GoN MoWR (2009)	DSRSL CBSL (2006)
2005–2010	6.0	9.0	8.0	6.0	4.2	6.6
2010–2015	5.5	7.0	8.0	6.3	5.5	7.8
2015–2020	5.0	7.8	8.0	6.5	5.8	7.4
2020–2025	4.5	7.8	8.0	6.0	6.0	7.4
2025–2030	4.5	7.8	8.0	6.0	6.0	7.4
Annual population growth rates (%) in 2005–2030						
Reference	GPRB BBS (2005)	RGoB NSB (2005b)	TERI (2006)	RoM MPND (2007); UN (2008)	GoN CBS (2003); UN (2008)	UN (2006)
2005–2010	1.40	1.85	1.51	1.99	2.08	0.88
2010–2015	1.20	1.70	1.44	1.68	1.90	0.73
2015–2020	1.30	1.35	1.23	1.55	1.78	0.51
2020–2025	1.20	1.01	1.01	1.33	1.65	0.29
2025–2030	1.10	0.82	0.84	0.97	1.52	0.15
% Urban and rural populations in 2005–2030						
Reference	GPRB BBS (2005)	RGoB NSB (2005b)	TERI (2006)[b]	RoM MPND (2007); UN (2008)	GoN CBS (2003); UN (2008)	UN (2006)
2005						
Rural	75.2	69.1	70.0	64.0	83.4	84.9
Urban	24.7	30.9	30.0	36.0	16.6	15.1
2010						
Rural	71.7	65.2	68.0	57.5	80.7	84.9
Urban	28.3	34.8	32.0	42.5	19.3	15.1

continued on next page

Table 16 *continued*

	Bangladesh	Bhutan	India	The Maldives	Nepal	Sri Lanka
2015						
Rural	67.7	61.1	66.0	51.5	78.2	84.3
Urban	32.2	38.9	34.0	48.5	21.8	15.7
2020						
Rural	63.7	58.0	64.0	46.1	74.1	83.1
Urban	36.4	42.0	36.0	53.9	25.9	16.9
2025						
Rural	59.3	54.7	62.0	41.4	70.1	81.2
Urban	40.7	45.3	38.0	58.6	29.9	18.8
2030						
Rural	54.7	51.1	60.0	37.6	67.5	78.6
Urban	45.3	48.9	40.0	62.4	32.5	21.4

[a] For India, TERI (2006) used a GDP growth rate of 7.3% during 2001–2006 and 8.0% from 2006 onward. A study using the TERI-MoEF model considers a compound annual GDP growth rate of 8.84% until 2030–2031 (GoI MoEF 2009).

[b] For India, the years 2005, 2010, 2015, 2020, 2025 and 2030 refer to 2006, 2011, 2016, 2021, 2026, and 2031, respectively.

Other factors or components that were considered in this study are summarized in the matrix below.

Factor/Component	Details
Energy resources or resource options	(i) Fossil fuels (petroleum products, natural gas, and coal); (ii) Renewable energy resources (such as tidal power, wind, solar energy, nuclear energy, fuelwood, agricultural residues, animal waste, and municipal solid waste); (iii) Biofuels (with 5% and 10% biodiesel, gasohol with 5%, 10%, and 85% bioethanol), hydrogen fuel, hybrid energy system (such as solar/diesel, wind/diesel, and wind/ liquefied natural gas)
Technology options for meeting future service demands	(i) Conventional technologies; (ii) Cleaner technologies (energy-efficient technologies, renewable energy technologies, and emerging technologies) In the residential and commercial sectors, emerging technologies include light-emitting diode (LED) lamps, and LED and plasma television sets. In agriculture, water pumps and land tillers with different efficiency levels and fuel requirements were considered. In the transport sector, efficient diesel vehicles, plug-in vehicles, solar/diesel hybrid vehicles, biodiesel vehicles (B5 and B10),[a] ethanol vehicles (E5, E10, and E85),[b] electric, and solar-powered electric vehicles were considered.
Power generation options (in South Asia, excluding India)	Conventional coal-fired steam plants; gas-fired combined cycle plants; gas-fired simple cycle plants; gas-fired steam turbine plants; hydropower plants; diesel plants; oil-fired simple cycle plants; and oil-fired steam turbine plants.
New electricity generation technologies	Conventional biomass steam power plant; biomass-based, integrated gasification, combined cycle (BIGCC) plant; supercritical coal steam power plant; pressurized fluidized bed combustion (PFBC) coal power plant; coal-based IGCC power plant; coal steam PFBC power plant with carbon capture and storage (CCS); coal-based IGCC power plant with CCS; gas-fired combined cycle with CCS; nuclear power plant (in Bangladesh); solar photovoltaics, wind, fuel cell-coal, fuel cell-gas, and municipal solid waste power plants.
Prices	Future prices of imported crude oil and coal from the "Projected Annual World Oil Price to 2030" (EIA 2009) Bangladesh: extraction cost of natural gas from Bangladesh Oil, Gas and Mineral Corporation (BOGMC 2005). Sri Lanka: price of liquefied natural gas (LNG) from the Department of Inland Revenue, Ministry of Finance and Planning Development All costs are expressed in constant 2005 dollars.

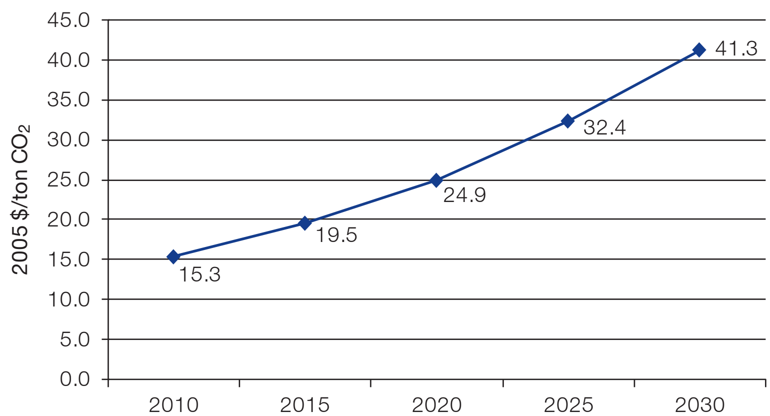
[a] B5 means a fuel mixture of 5% biofuel and 95% diesel. Similarly, B10 means a fuel mixture of 10% biofuel and 90% diesel.

[b] E5, E10, and E85 mean a fuel mixture of 5%, 10%, and 85% of ethanol; and 95%, 90%, and 15% of gasoline, respectively.

Carbon-Tax Scenario

The study's second scenario analyzed the evolutions of the energy mix, electricity generation system, GHG emissions, and energy system cost under an alternative climate policy (in the form of a carbon tax/carbon price) for achieving the global stabilization target of CO_2 concentration. Following Edmonds (2009, personal communication), the carbon price profile[15] would be at $15 per ton CO_2 (at constant 2005 prices) in 2010, $25 per ton CO_2 in 2020, and attain a value of $41 per ton CO_2 by 2030 (Figure 4), all other conditions remaining the same as in the base case. The carbon price profile is based on the outputs obtained from the global Second Generation Model (SGM). Similar carbon price profile has also been used by Shukla et al. (2008) for GHG stabilization target of 550 ppmv of CO_2e.

Figure 4 **Carbon Price Profile under the Carbon Tax Scenario**



Source: Edmonds, J. 2009. personal communication. PNNL, Richmond, Washington.

Related Project Activities

The conduct of this study involved a number of steps done for each of the five South Asia DMCs: (i) preparing an inventory of past and current emission levels of carbon dioxide (CO_2) and other GHGs; (ii) construction of future scenarios on population and gross domestic product (GDP) growth and technological development/penetration for the next 20 years (until 2030); (iii) estimation of national future demands for energy-using services for the same time period, corresponding to changes in population, GDP, and technological penetration under each scenario; (iv) estimation of future national levels of activities not using energy, but contributing to GHG emissions over the next 20 years (until 2030) under each scenario; (v) estimation of emissions of CO_2 and other GHGs from energy and non-energy-related activities for the same time period under the reference

15 The carbon price profile for CO_2 stabilization level at 450 ppmv is considered to be closer to the 550 ppmv stabilization level of CO_2 equivalent (CO_2e), accounting for all GHGs (Clarke et. al. 2008). This study considers the 2010–2030 carbon price profile as the carbon tax profile in the same period.

and other scenarios; and (vi) identification of promising clean technologies and options, which may include improvements in energy efficiency, switching to alternative energy sources with lower GHG emissions, emerging technologies (e.g., carbon capture and storage), and other options in activities not related to energy use.

The mitigation analysis was carried out through (i) scoping and literature review of international, regional, and country-specific studies and research to obtain country and regional data on climate change and future trends; (ii) regional consultations and national experts workshops; and (iii) GHG profiling/data analysis and identification of technology gaps, followed by mapping future energy demand under different global scenarios of the Intergovernmental Panel on Climate Change (IPCC) and analysis of marginal abatement cost curves.

The scoping and literature review mapped the current regional and national climate change situation, including trends and possible local impacts of climate change, GHG emission levels, existing climate change policies, and clean technologies and options available domestically for each country. The scoping activity assembled regional and country data and information regarding vulnerable areas/sectors (e.g., agriculture, water resources, and human health) and segments of population (e.g., the poor, non-poor, and rural and urban populations); current GHG emissions and projections (including key sources and sinks); potential clean technologies and options and their suitability to each of the participating countries; national laws, agreements or regulations implemented, adopted, proposed, or under preparation; and regional initiatives to address climate change issues. The data were collected from published and unpublished reports, journal articles, working papers, etc., by academics, government agencies, research institutes, international organizations, and nongovernment organizations.

Limitations of the Study

The study applied a bottom-up energy system model based on the MARKAL framework, which is extremely data intensive in terms of technology characteristics, resource availability, and service demands. To the extent available, country-specific data on technology characteristics and prices were used. In the absence of such data, those from another country in the region, where similar technologies are in use, were adopted.

One of the key drivers of the model is the future demand for end-use services in different sectors (e.g., passenger-kilometer of transport services, useful energy requirements for heating, and amount of lighting needed). The projection of future service demands would ideally require service demand modeling, e.g., an econometric estimation of the relationship between a service demand and its explanatory variables. However, the limited data available under the present study did not allow such estimation in most of the countries. This required simplifying some assumptions to estimate future service demands. For example, in several cases, service demand per unit of GDP was assumed to remain the same as that in the base year and that it is not affected by energy prices and service-providing devices; both are quite a simplification.

This study did not estimate the relationship between technology penetration rate and its underlying factors. Assumptions were instead made about the limits on future penetration levels of various technologies, particularly the cleaner options.

In the carbon-tax scenario, theoretically, the introduction of carbon tax is likely to affect the costs (or prices) of services that use fossil fuels and thereby the level of service demands. This would again require a service-demand model with fuel price as an explanatory variable. No such modeling was done in this study and service demands were assumed to be insensitive to carbon tax. Further, the effects of carbon tax on the outputs of different sectors of the economy were beyond the scope of the bottom-up energy system model used in the present study.

A carbon tax generates revenue that is normally recycled through subsidies for clean technologies. Recycling carbon tax revenue affects the choice of technologies and level of energy consumption. However, this study did not consider recycling carbon tax revenue. In addition, the study considered only the direct (or internal) cost of using fuels (through their prices), and did not include the external costs of energy combustion.

In analyzing the GHG abatement potential and cost of cleaner options, the number of abatement options and their level of penetration to replace the conventional (i.e., less energy-efficient or more carbon-intensive) options in the base case were considered based on the modeler's best judgment and not on a detailed analysis.

Lastly, a major limitation of the present study is the exclusion of the possibility of cross-border energy resource development and trade in South Asia. The opportunity offered through a regional energy trade mechanism for one country to use cleaner energy resources available in other countries within the region is not captured in the model. Thus, the economic efficiency, energy security, and environmental co-benefits of regional energy resource development and trade were not analyzed.

4 Options and Costs to Reduce GHG Emissions in 2005–2030

This chapter discusses the GHG emissions and clean technology and resource options for GHG abatement from both energy- and non-energy-related activities in South Asia during 2005–2030. It also analyzes the abatement cost and GHG mitigation potential of selected clean technology and resource options in 2020. In the case of energy-related activities, energy system development and GHG emissions are analyzed under a base case (or reference scenario) and a carbon tax for Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka using country-specific energy system models. In the case of non-energy related activities, the analysis of GHG emissions and abatement potential of cleaner options is focused on agriculture, forestry, industrial processes, and waste in Bangladesh, Bhutan, Nepal, and Sri Lanka. The results from these individual country studies form the basis of the regional analysis presented in this chapter. The India-specific information relevant for the regional analysis came from an intensive review of existing studies available in the literature.

Energy-Using Activities

Base Case

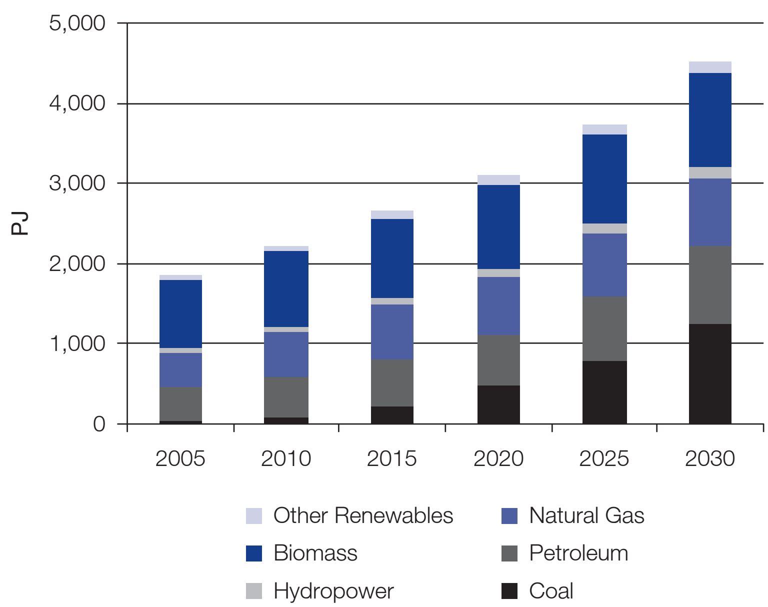
Structure of Energy Supply (Energy Development)

Figures 5 and 6 show the structure of total primary energy supply (TPES) in South Asia (excluding India)[16] during 2005–2030. In 2005, South Asia's TPES was 1,866 petajoules (PJ), of which biomass had the largest share (45.6%), and oil and gas had similar contributions (about 23.0%). Coal, hydropower, and other renewable resources together accounted for less than 10% of TPES in that year.

In the base case, South Asia is projected to become more fossil fuel dependent (Table 17). The share of coal in the energy mix of the region is estimated to increase from 2.0% in 2005 to 27.6% by 2030 mainly due to the high and growing coal dependence of Bangladesh. Although the share of oil is expected to decline from 22.9% to 21.7% during 2005–2030, it would remain a significant source of energy. Similarly, the shares of biomass and natural gas in the region's TPES are projected to decline, although their use in the absolute terms would increase during 2005–2030.

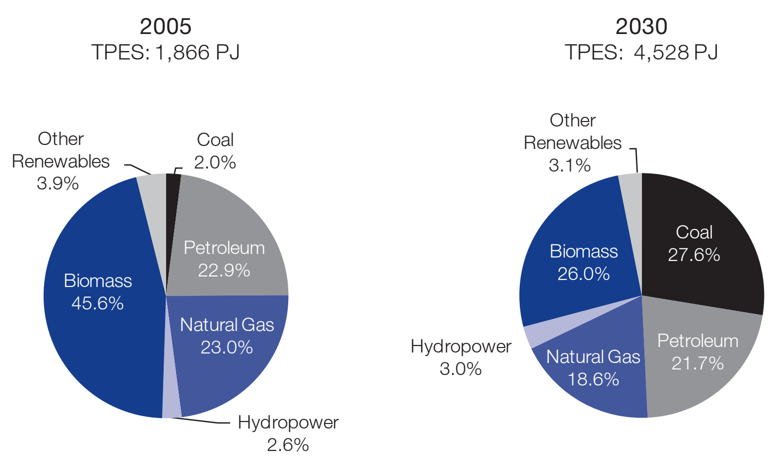
[16] Unless otherwise stated, "South Asia" in this chapter will refer to South Asia excluding India (i.e., Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka).

Figure 5 **Total Primary Energy Supply in South Asia (Excluding India), 2005–2030**



PJ = petajoule.
Source: RECCSA1 country studies (unpublished).

Figure 6 **Structure of Total Primary Energy Supply in South Asia (Excluding India), 2005 and 2030**



PJ = petajoule, TPES = total primary energy supply.
Source: RECCSA1 country studies (unpublished).

Table 17 **Total Primary Energy Supply by Source under Base Case and Carbon Tax, South Asia** (%)

	Biomass and Waste	Coal	Hydropower	Liquified Petroleum Gas (LPG)	Natural Gas	Nuclear	Petroleum Products	Other Renewable Resources	TPES (PJ)
Bangladesh									
2005	30.9	2.6	1.8	0.1	40.9	0.0	18.9	4.8	1,050.4
2030 Base case	14.7	38.2	1.0	0.0	31.7	0.0	12.4	1.9	2,657.0
2030 Carbon tax	15.8	12.6	1.4	0.0	49.1	4.8	12.3	4.0	2,685.1
Bhutan									
2005	54.1	6.7	21.9	1.0	0.0	0.0	15.7	0.6	17.8
2030 Base case	27.5	11.7	31.4	0.6	0.0	0.0	27.8	1.1	88.2
2030 Carbon tax	29.1	12.4	30.0	0.6	0.0	0.0	27.6	1.1	83.4
India									
2005	29.3	38.6	1.7	–	5.4	0.9	23.9	0.2	22,567.0
2030 Base case	14.9	47.7	1.7	–	7.2	2.5	25.3	0.7	54,387.0
2030 Carbon tax	*	*	*	*	*	*	*	*	*
The Maldives									
2005	1.3	0.0	0.0	3.4	0.0	0.0	95.3	0.1	9.2
2030 Base case	1.7	0.0	0.0	3.3	0.0	0.0	83.9	11.1	45.8
2030 Carbon tax	1.7	0.0	0.0	3.9	0.0	0.0	81.9	12.3	46.3
Nepal									
2005	86.2	2.2	2.4	1.1	0.0	0.0	7.1	1.0	374.7
2030 Base case	59.1	5.2	11.1	1.7	0.0	0.0	17.9	4.9	579.5
2030 Carbon tax	59.4	5.2	11.6	1.7	0.0	0.0	17.2	4.5	576.0
Sri Lanka									
2005	46.6	0.2	8.4	2.6	0.0	0.0	42.1	0.0	413.6
2030 Base case	36.3	16.6	3.8	1.6	7.3	0.0	31.8	2.5	1,157.9
2030 Carbon tax	54.4	1.8	3.6	2.0	6.9	0.0	28.8	2.4	1,221.0

continued on next page

Table 17 *continued*

	Biomass and Waste	Coal	Hydropower	Liquified Petroleum Gas (LPG)	Natural Gas	Nuclear	Petroleum Products	Other Renewable Resources	TPES (PJ)
South Asia (excluding India)									
2005	45.6	2.0	3.6	0.9	23.0	0.0	22.0	2.9	**1,865.7**
2030 Base case	26.0	27.6	3.6	0.7	20.5	0.0	19.1	2.5	**4,528.4**
2030 Carbon tax	31.5	8.7	3.8	0.8	30.5	2.8	18.2	3.7	**4,611.8**
South Asia (including India)									
2005	30.6	35.8	1.8	0.1	6.7	0.9	23.8	0.4	**24,432.7**
2030 Base case	15.8	46.2	1.8	0.1	8.2	2.3	24.8	0.8	**58,915.4**
2030 Carbon tax	*	*	*	*	*	*	*	*	*

PJ = petajoule, TPES = total primary energy supply.

* No analysis under the carbon-tax scenario was done for India.

Notes: Other renewable resources by country are: Bangladesh—Biofuels, municipal solid waste (MSW), solar power, wind. Bhutan—Biogas, biofuels, MSW, solar power. The Maldives—Biogas, biofuels, MSW, solar power, wind. Nepal—Biogas, biofuels, MSW, solar power. Sri Lanka—Biofuels, MSW, solar power, wind.

Source: RECCSA1 country reports (unpublished)

Source of India data: IEA (International Energy Agency). 2007. *World Energy Outlook 2007, [the People's Republic of] China and India Insights*. OECD/IEA. Paris.

Estimates of future TPES in India vary widely among different studies. TERI (2006) estimated India's TPES (excluding biomass energy) at 16,412 PJ in 2005, increasing to 88,886 PJ in 2030 at a compounded annual growth rate (CAGR) of 7.0%. However, the study omitted biomass, which accounts for up to a third of present TPES. IEA (2007) estimated that India's TPES would increase at a CAGR of 3.6% from 22,148 PJ in 2005 to 54,387 PJ in 2030. The share of biomass in the TPES was 29% in 2005 and would decrease to 15% by 2030, whereas the share of coal would increase from 39% in 2005 to 48% in 2030. The share of oil (25%) in India's TPES in 2030 would be slightly higher than that in 2005. Another study (GoI MoEF 2009) found that India's commercial energy use in 2030–2031 would vary from 45,511 PJ to 89,974 PJ across five different climate modeling studies. The different estimated values of the future TPES reflect the five studies' differences in the models used and assumptions made on GDP and population growth rates and other factors.[17]

Under the base case, South Asia's energy intensity is projected to decrease from 1.63 t of oil equivalent (toe) per $1,000 (PPP) in 2005 to 1.13 toe per $1,000 (PPP) in 2030 (Table 18). The energy intensity of India has been estimated to decrease from 0.15 toe per $1,000 (PPP) in 2005 to 0.12 toe per $1,000 (PPP) in 2030 (TERI 2006).[18]

Table 18 **Energy Intensity, South Asia** (toe per $1,000 2005 [PPP])

	2005	2010	2015	2020	2025	2030
South Asia (excluding India)	1.63	1.48	1.32	1.21	1.14	1.13
India	0.15	0.14	0.13	0.13	0.12	0.12

PPP = purchasing power parity, toe = ton of oil equivalent.

Note: For India, the data for 2005, 2010, 2015, 2020, 2025, and 2030 refers to 2006, 2011, 2016, 2021, 2026, and 2031, respectively. The energy intensity of India has been estimated to decline from 0.11 toe/$1,000 (PPP) in 2001/02 to 0.06 toe/$1,000 (PPP) in 2031/32 (GoI MoEF 2009).

Source: TERI (The Energy and Resources Institute). 2006. *National Energy Map for India: Technology Vision 2030*. Office of the Principal Scientific Adviser. New Delhi.

Electricity Generation

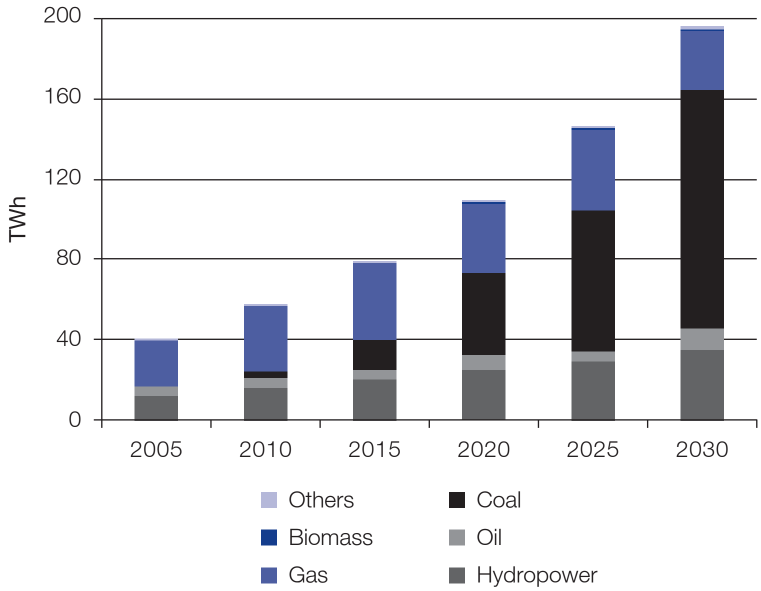
Figure 7 shows the contribution of fuel sources to electricity generation in South Asia during 2005–2030. In 2005, natural gas was the most important source at 57.7% of the total, followed by hydropower, oil, and other renewable resources (i.e., municipal solid waste, solar, and wind). Apart from India, Bangladesh was the only country in the region to use natural gas to generate electricity in 2005.

Under the base case, the share of oil and gas in power generation in South Asia is estimated to decline, while that of coal is estimated to grow from almost zero to 61% during 2005–2030 (Figure 8 and Table 19). At the same time, the share of hydropower

[17] Across the five modeling studies compiled by GoI MoEF (2009), the GDP growth rates ranged from 7.66% to 8.84%, while TERI (2006) considered an 8% GDP growth rate and IEA (2007) assumed it at 7.2% during 2005–2015 and 5.8% during 2015–2030. TERI (2006) assumed a population growth rate that varies from 1.37% to 0.92% during 2001–2031, while IEA (2007) assumed 1.4% for 2005–2015 and 1.0% during 2015–2030.

[18] The 1993 constant GDP of India was converted to 2005 constant GDP based on purchasing power parity (PPP) using the PPP/market exchange rate ratio given in the World Development Indicators (http://data.worldbank.org/indicator/PA.NUS.PPPC.RF?page=1) for the calculation of the energy intensity data in the respective years.

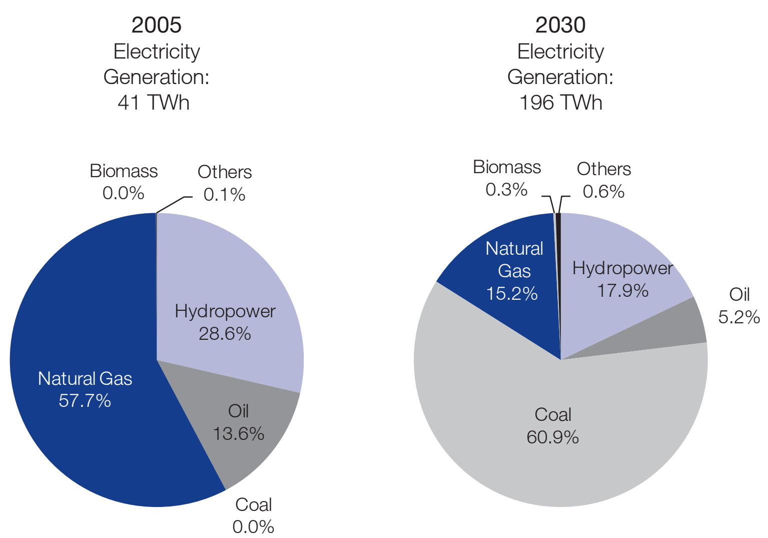
Figure 7 **Electricity Generation in South Asia (Excluding India), 2005–2030**



Note: One terawatt-hour (TWh) is 1,012 kilowatt-hours. India's future electricity generation by fuel source was not included in this figure due to lack of such estimates in TERI (2006).

Source: TERI (The Energy and Resources Institute). 2006. *National Energy Map for India: Technology Vision 2030*. Office of the Principal Scientific Adviser. New Delhi.

Figure 8 **Electricity Generation Share by Fuel Type in South Asia (Excluding India), 2005 and 2030**



TWh = terawatt-hour.

Source: RECCSA1 country studies (unpublished).

Table 19 **Share in Electricity Generation by Fuel Source under Base Case and Carbon Tax, South Asia** (%)

	Biomass and Waste	Coal	Hydropower	Liquefied Petroleum Gas (LPG)	Natural Gas	Nuclear	Petroleum Products	Other Renewable Resources	Total Electricity Supply (TWh)
Bangladesh									
2005	0.0	0.0	6.0	0.0	94.0	0.0	0.0	0.0	25.1
2030 Base case	0.0	84.3	1.9	0.0	13.8	0.0	0.0	0.0	118.7
2030 Carbon tax	0.0	24.0	1.9	0.0	61.3	9.8	0.0	3.1	117.6
Bhutan									
2005	0.0	0.0	99.9	0.0	0.0	0.0	0.1	0.0	2.86
2030 Base case	0.0	0.0	99.4	0.0	0.0	0.0	0.0	0.6	8.30
2030 Carbon tax	0.0	0.0	99.4	0.0	0.0	0.0	0.0	0.6	6.99
India									
2005	0.3	68.8	14.3	0.0	8.9	2.4	4.4	0.9	698.0
2030 Base case	1.0	70.6	9.3	0.0	10.5	4.6	1.1	2.8	2,774.0
2030 Carbon tax	*	*	*	*	*	*	*	*	*
The Maldives									
2005	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.5
2030 Base case	0.0	0.0	0.0	0.0	0.0	0.0	75.0	25.0	1.6
2030 Carbon tax	0.0	0.0	0.0	0.0	0.0	0.0	76.6	23.4	1.58
Nepal									
2005	0.0	0.0	96.2	0.0	0.0	0.0	3.0	0.8	2.66
2030 Base case	0.0	0.0	99.5	0.0	0.0	0.0	0.2	0.3	18.58
2030 Carbon tax	0.0	0.0	99.4	0.0	0.0	0.0	0.3	0.3	19.29
Sri Lanka									
2005	0.0	0.0	49.0	0.0	0.0	0.0	51.0	0.1	9.8
2030 Base case	1.0	39.4	12.7	0.0	27.6	0.0	18.2	1.2	49.0
2030 Carbon tax	36.7	3.7	12.7	0.0	27.8	5.9	12.2	1.3	49.0

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Table 19 *continued*

	Biomass and Waste	Coal	Hydropower	Liquefied Petroleum Gas (LPG)	Natural Gas	Nuclear	Petroleum Products	Other Renewable Resources	Total Electricity Supply (TWh)
South Asia (excluding India)									
2005	0.0	0.0	28.7	0.0	57.6	0.0	13.6	0.1	**41.0**
2030 Base case	0.3	60.9	17.9	0.0	15.2	0.0	5.2	0.6	**196.2**
2030 Carbon tax	9.3	15.4	17.8	0.0	44.1	7.4	3.7	2.4	**194.5**
South Asia (including India)									
2005	0.3	65.0	15.1	0.0	11.6	2.3	5.0	0.8	**739.0**
2030 Base case	1.0	69.9	9.9	0.0	10.8	4.3	1.4	2.7	**2,970.2**
2030 Carbon tax	*	*	*	*	*	*	*	*	*

TWh = terawatt-hour.

* No analysis under the carbon-tax scenario was done for India.

Notes: Other renewable resources by country are: Bangladesh—Biofuels, municipal solid waste (MSW), solar power, wind. Bhutan—Biogas, biofuels, MSW, solar power. The Maldives—Biogas, biofuels, MSW, solar power, wind. Nepal—Biogas, biofuels, MSW, solar power. Sri Lanka—Biofuels, MSW, solar power, wind.

Source: RECCSA1 country reports (unpublished)

Source of India data: IEA (International Energy Agency). 2007. *World Energy Outlook 2007, [the People's Republic of] China and India Insights*. OECD/IEA. Paris.

is estimated to decline. A major reason behind this could be the fact that no regional trade of electricity has been considered in the present analysis. The share of electricity generated from other renewable energy resources, such as biomass, municipal solid waste (MSW), wind, and solar power, has been estimated to increase slightly.

Including India, the share of biomass, coal, nuclear energy, and other renewable sources in generating electricity for South Asia in 2030 will increase from their respective 2005 levels (Table 19). In contrast, the contribution of hydropower, natural gas, and petroleum products to the region's electricity generation will decline between the two periods.

Sector Energy Use/Consumption

Table 20 presents energy consumption by sector in South Asia, both including and excluding India. The total sector energy consumption in the region, including India, would increase from 12,856.7 PJ in 2005 to 66,724.2 PJ in 2030, at a CAGR of 6.8%. The industrial, transport, and residential sectors (in this order) are consistently the top three major energy-consuming sectors in the region. The transport and industrial sectors are also the two fastest-growing sectors in terms of energy use, with a ratio of 6.6 and 5.8, respectively, between 2005 and 2030. The industrial sector accounted for half of the total final energy consumption in South Asia (including India) in 2005 and its share is estimated to increase slightly (to 55.4%) by 2030; similarly, the share of the transport sector would increase from 23.5% in 2005 to 29.9% in 2030. The total final energy consumption of the residential sector would decrease from 17.4% in 2005 to 9.9% in 2030. The agriculture sector accounted for 5.9% of total final energy use in 2005, which would decrease to 1.7% in 2030. Note that while Table 20 shows the trends, biomass energy data for India are not included.

Table 20 **Sector Energy Use in South Asia** (PJ)

Sector	2005	2010	2015	2020	2025	2030	Ratio 2030/2005
Including India*							
Agriculture	757.1	805.9	895.9	984.5	1,030.8	1,119.2	1.5
Commercial	411.2	547.2	778.2	1,054.4	1,460.6	2,044.2	5.0
Industrial	6,423.0	8,921.0	12,607.6	17,892.7	25,573.4	36,976.8	5.8
Residential	2,240.7	2,906.9	3,682.6	4,654.8	5,595.2	6,634.7	3.0
Transport	3,024.8	4,712.2	7,083.5	10,094.4	14,254.7	19,949.4	6.6
Total	**12,856.7**	**17,893.3**	**25,047.8**	**34,680.7**	**47,914.7**	**66,724.2**	5.2
Excluding India							
Agriculture	45.3	52.3	58.5	63.4	67.8	72.5	1.6
Commercial	34.4	44.8	66.4	91.4	120.8	160.1	4.7
Industrial	352.1	463.7	633.4	852.4	1,122.5	1,472.7	4.2
Residential	900.9	981.0	1,044.9	1,096.0	1,157.2	1,233.7	1.4
Transport	219.6	274.2	342.8	422.9	522.0	648.3	3.0
Total	1,552.3	1,816.0	2,146.0	2,526.1	2,990.3	3,587.3	2.3

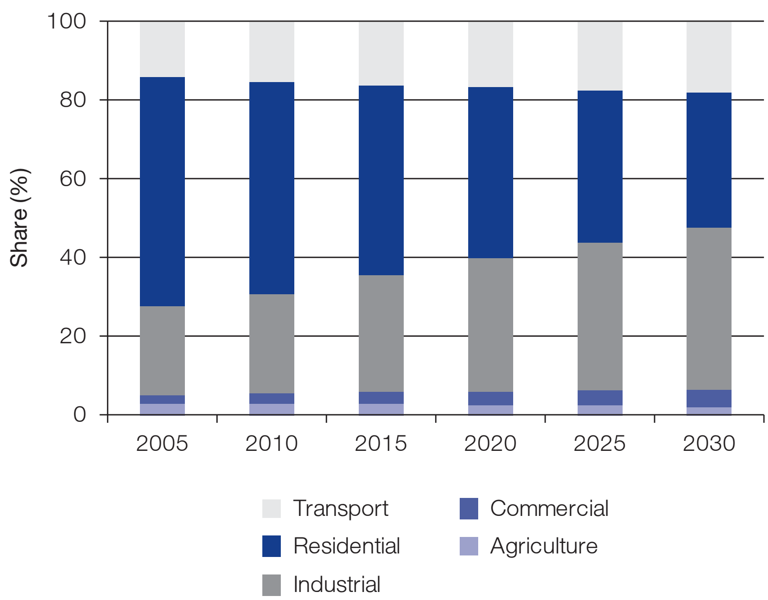
PJ = petajoule.

* Note: For India, the data of 2005, 2010, 2015, 2020, 2025, and 2030 refer to 2006, 2011, 2016, 2021, 2026, and 2031, respectively. The sector energy consumption for India does not include biomass energy consumption.

Source: TERI (The Energy and Resources Institute). 2006. *National Energy Map for India: Technology Vision 2030*. Office of the Principal Scientific Adviser. New Delhi.

Excluding India, South Asia's energy use across sectors would increase at a CAGR of 3.4% from 1,552.3 PJ in 2005 to 3,587.3 PJ (Table 20). The residential and industrial sectors are the top two energy-consuming sectors, with the transport sector as a far third. In 2005, the residential, industrial, and transport sectors shared 58.0%, 22.7%, and 14.1% of South Asia's total final energy use, respectively (Figure 9). The share in energy use of the residential sector is estimated to decrease to 34.4% by 2030. The industrial sector would then become the largest consumer of energy.

Figure 9 Sector Share in Total Final Energy Consumption, South Asia (Excluding India), 2005–2030



Source: RECCSA1 country studies (unpublished).

Table 21 presents the base case estimated total final energy consumption (TFEC) by sector and country in South Asia for 2005 and 2030.

Energy-Related GHG Emissions

The total energy-related GHG emissions from South Asia (excluding India) would increase at a CAGR of 5.9% from around 58.2 million t CO_2e in 2005 to 244.7 million t by 2030 (Figure 10). In 2005, CO_2 emissions were around 95.6% of the total energy-related GHG emissions from the region, followed by methane (CH_4) (3.6%) and nitrous oxide (N_2O) (0.8%) emissions. By 2030, these shares are estimated to be 98.6%, 0.9%, and 0.5% respectively.

In 2005, electricity (power) generation was the single largest energy-related GHG-emitting activity in South Asia (excluding India), accounting for 30.0% of the total energy-related GHG emissions, followed by the transport and industry sectors (Figure 11). The residential, agricultural, and commercial sectors together accounted for about 21% of total energy-related GHG emissions in 2005. In 2030, the power generation sector would

Table 21 **Sector Share in Total Final Energy Consumption under Base Case and Carbon Tax, South Asia** (%)

	Agriculture	Commercial	Industrial	Residential	Transport	Total TFEC (PJ)
Bangladesh						
2005	4.9	1.6	29.9	47.7	15.9	855.1
2030 Base case	2.9	2.3	49.6	32.5	12.7	2,009.2
2030 Carbon tax	3.0	3.3	50.1	30.8	12.8	1,989.3
Bhutan						
2005	1.3	10.4	22.7	52.6	13.6	15.4
2030 Base case	0.6	13.4	41.9	13.2	31.1	71.1
2030 Carbon tax	0.6	13.4	41.9	13.2	31.1	71.1
India						
2005	6.3	3.3	53.7	11.9	24.8	11,304.4
2030 Base case	1.7	3.0	56.2	8.6	30.6	63,136.9
2030 Carbon tax	*	*	*	*	*	*
The Maldives						
2005	0.0	19.0	13.8	15.5	50.0	5.8
2030 Base case	0.0	9.9	7.4	11.9	70.8	35.3
2030 Carbon tax	0.0	9.9	7.7	11.9	70.7	35.2
Nepal						
2005	0.8	1.4	3.3	90.7	3.6	365.0
2030 Base case	2.1	6.4	8.3	69.8	13.7	533.0
2030 Carbon tax	2.1	6.4	8.1	70.2	13.2	530.0
Sri Lanka						
2005	0.2	4.2	25.7	48.9	20.9	311.9
2030 Base case	0.2	7.2	42.5	20.9	29.2	937.8
2030 Carbon tax	0.2	7.2	46.6	16.5	29.5	928.0
South Asia (excluding India)						
2005	2.9	2.2	22.7	58.0	14.1	1,552.3
2030 Base case	2.0	4.5	41.0	34.4	18.1	3,587.3
2030 Carbon tax	2.0	5.1	42.3	32.4	18.2	3,553.6
South Asia (including India)						
2005	5.9	3.2	50.0	17.4	23.5	12,856.7
2030 Base case	1.7	3.1	55.4	9.9	29.9	66,724.2
2030 Carbon tax	*	*	*	*	*	*

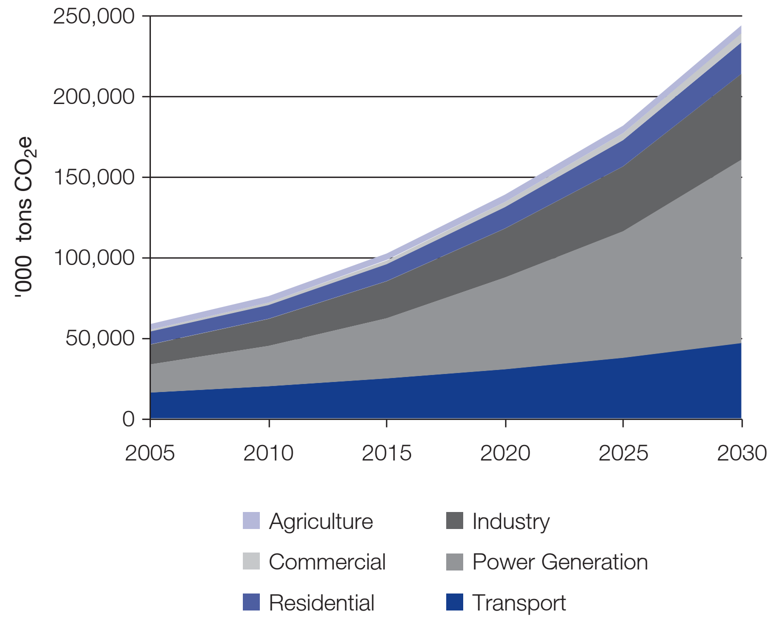
PJ = petajoule, TFEC = total final energy consumption.

* No analysis under the carbon-tax scenario was done for India.

Notes: For India, the 2005 and 2030 data refers to 2006 and 2031, respectively. The sector energy consumption for India does not include biomass energy consumption (TERI 2006).

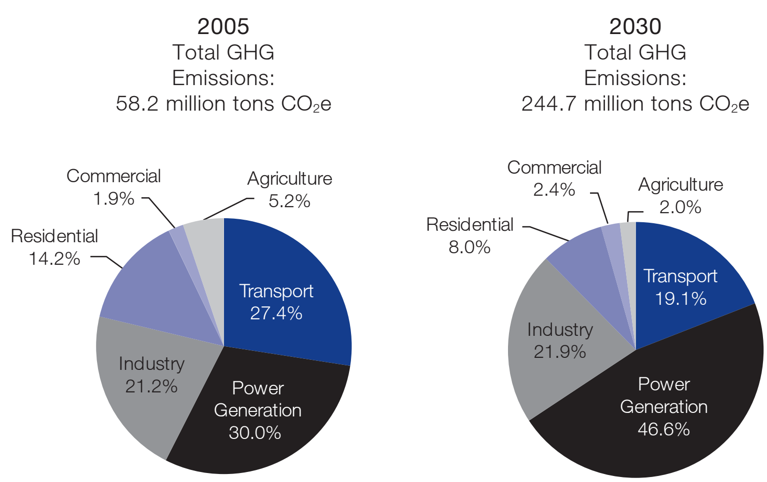
Source: RECCSA1 country reports (unpublished).

Figure 10 **Sector GHG Emissions, South Asia (Excluding India), 2005–2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.
Source: RECCSA1 country studies (unpublished).

Figure 11 **Sector Shares in GHG Emissions, South Asia (Excluding India), 2005 and 2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.
Source: RECCSA1 country studies (unpublished).

still contribute the most (46.6%) to the total energy-related GHG emission, followed by the industry, transport, residential, commercial, and agriculture sectors (in this order). The shares of the transport and residential sectors would decline mainly due to the adoption of cleaner and more efficient vehicles and cooking stoves, respectively. Table 22 shows the base case estimated total GHG emissions by energy-using activities in 2005 and 2030 for South Asia (excluding India).

For India, GoI MoEF (2009) estimated the total CO_2 emission in 2031/32 to be 4,900 million t. Another study (Shukla 2006) estimated that the country's GHG emissions would grow from 1,454 million t CO_2e in 2000 to 2,839 million t CO_2e in 2020 and 3,507 million t CO_2e in 2030 under IPCC scenario A2. The share of CO_2 in GHG emissions would increase from 66% in 2000 to 73% in 2030, while that of CH_4 would decline from 27% in 2000 to 15% in 2030. A study by McKinsey and Company (2009) estimated GHG emissions of around 1,570 million t CO_2e in India in 2005, which would increase to around 3,312 million t CO_2e and 5,742 million t CO_2e by 2020 and 2030, respectively. IEA (2007) estimated that CO_2 emissions from energy use in India would increase from around 1,147 million t in 2005 to 1,804 million t and 3,314 million t in 2015 and 2030, respectively.

The CO_2 intensity of South Asia would slightly increase from 0.18 kg CO_2 per $ GDP (PPP) in 2005 to 0.20 kg CO_2 per $ GDP (PPP) in 2030. The CO_2 intensity of India[19] was 0.18 kg CO_2 per $ GDP (PPP) in 2001, and estimated by different climate modeling studies to range at 0.15–0.28 kg per $ GDP (PPP) by 2031.

Cost-Effective Clean Energy Options

Several of the energy-efficient options considered in the study are already found cost-effective under the base case in Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka. The following matrix summarizes these options by sector.

Sector	Cost-Effective Energy-Efficient Options for Greenhouse Gas Emission Mitigation
Agriculture	Energy-efficient diesel fishing boats; efficient diesel pumps; efficient tillers; efficient electric pumps; efficient diesel tractors; efficient electric threshers
Industry	Efficient fuelwood gasifier; efficient smelting furnace; improved arc furnace; energy-efficient motors; biomass boilers; efficient coal boilers; efficient Hoffman kilns in the brick industry; improved and energy-efficient boilers in textile, fertilizer, and paddy parboiling industries; efficient continuous process in the sugar industry
Residential	Improved fuelwood cooking stove; solar cooking stove; electric cooking stove; efficient liquefied petroleum gas (LPG) and solar water heaters; energy efficient fan and refrigerator; efficient air-conditioners, compact fluorescent lamps, light-emitting diode (LED) lamps
Power generation	Coal-based integrated gasification combined cycle power plant; municipal solid waste-based and wind energy power generation options
Transport	Efficient diesel truck, efficient diesel and electric buses, biodiesel (B5)-based bus, light trucks and three-wheelers; gasohol (E5)-using taxi, two-wheelers and three-wheelers; efficient gasoline two-wheelers, plug-in hybrid gasoline taxi; efficient diesel and efficient electric railway locomotives; and efficient diesel water vessels

19 The CO_2 intensity of GDP for India was estimated to be 0.37 per $ GDP at PPP in 2003–2004; the estimated intensity in 2031–2032 is found to vary in the range of 0.18-0.28 kg CO_2 per $ GDP at PPP across four modeling studies (GoI MoEF 2009). The CO_2 intensity of 0.18 kg CO_2 in 2031–2032, based on a TERI-MOEF study as reported in GoI MoEF (2009), has been used for India while calculating the total CO_2 intensity of the whole region (the six countries) for 2030.

Table 22 **Contributions to Total GHG Emissions of Energy-Using Sectors under Base Case and Carbon Tax, South Asia** (%)

	Agriculture	Commercial	Industrial	Power	Residential	Transport	Total GHG Emissions (million t CO_2e)
Bangladesh							
2005	6.7	1.2	23.5	33.5	11.1	24.0	41.32
2030 Base case	2.5	1.4	26.4	50.2	8.8	10.7	168.30
2030 Carbon tax	3.1	0.8	33.2	42.7	6.8	13.4	134.15
Bhutan							
2005	0.3	7.2	38.7	0.3	7.2	46.2	0.33
2030 Base case	0.1	1.6	39.4	0.2	1.2	57.5	2.86
2030 Carbon tax	0.1	1.6	39.5	0.0	1.2	57.6	2.85
India[a]							
2005	*	*	*	*	*	*	1,147.00
2030 Base case	*	*	*	*	*	*	3,314.00
2030 Carbon tax	*	*	*	*	*	*	
The Maldives							
2005	0.0	0.1	5.9	58.8	2.9	30.9	0.68
2030 Base case	0.0	0.2	4.4	31.9	2.3	61.7	2.98
2030 Carbon tax	0.0	0.2	4.4	31.9	2.4	61.4	2.95
Nepal							
2005	4.1	3.9	16.9	1.5	56.1	17.8	5.40
2030 Base case	5.0	5.5	23.3	0.5	27.6	38.1	13.53
2030 Carbon tax	5.1	5.7	23.7	0.8	28.0	36.7	13.16

continued on next page

Table 22 *continued*

	Agriculture	Commercial	Industrial	Power	Residential	Transport	Total GHG Emissions (million t CO_2e)
Sri Lanka							
2005	0.4	3.8	14.8	30.4	5.4	45.1	10.51
2030 Base case	0.2	4.7	8.1	50.1	1.6	35.2	57.07
2030 Carbon tax	0.4	7.1	9.0	27.0	3.4	53.1	37.80
South Asia (excluding India)							
2005	5.2	1.9	21.2	30.0	14.2	27.4	58.24
2030 Base case	2.0	2.4	21.9	46.6	8.0	19.1	244.75
2030 Carbon tax	2.6	2.4	27.4	35.9	7.5	24.3	190.91

GHG = greenhouse gases, t CO_2e = tons carbon dioxide equivalent.

* No detailed/sector data available for India.

Note: For India, the total GHG emissions are CO_2 emissions only (IEA 2007).

Source: RECCSA1 country studies (unpublished).

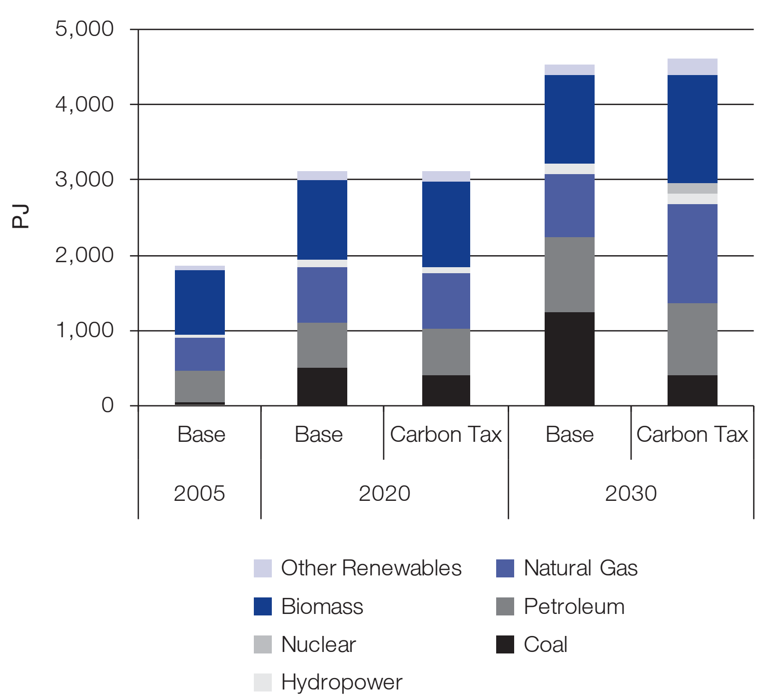
It should be noted that if the above-mentioned renewable and energy-efficient options were not used, the total cumulative GHG emission from South Asia (excluding India) during 2005–2030 would be 3.2% higher at 4,141 million t compared to 4,011 million t in the base case. This emphasizes the importance of promoting the use of energy-efficient options as a GHG mitigation strategy in South Asia even without a carbon price policy. Although these options are cost-effective, most of them are yet to be adopted due to various non-cost barriers.

Carbon-Tax Scenario

Total Primary Energy Supply

Under a carbon tax, the total primary energy supply of South Asia (excluding India) would be lower than that in the base case by 0.1% in 2020 and higher by 1.8% in 2030. The primary energy supply mix of these countries would move toward more aggressive use of natural gas, hydropower, biomass, and other renewable resources[20] (Figure 12). Coal consumption would be reduced by 18.4% in 2020 and 68.0% in 2030. The use of petroleum products under a carbon tax would also be reduced by almost 3% in 2030. Table 17 includes the estimated fuel shares in total primary energy supply in South Asia under the base case and a carbon tax.

Figure 12 **Primary Energy Supply under the Base Case and Carbon Tax in South Asia (Excluding India)**



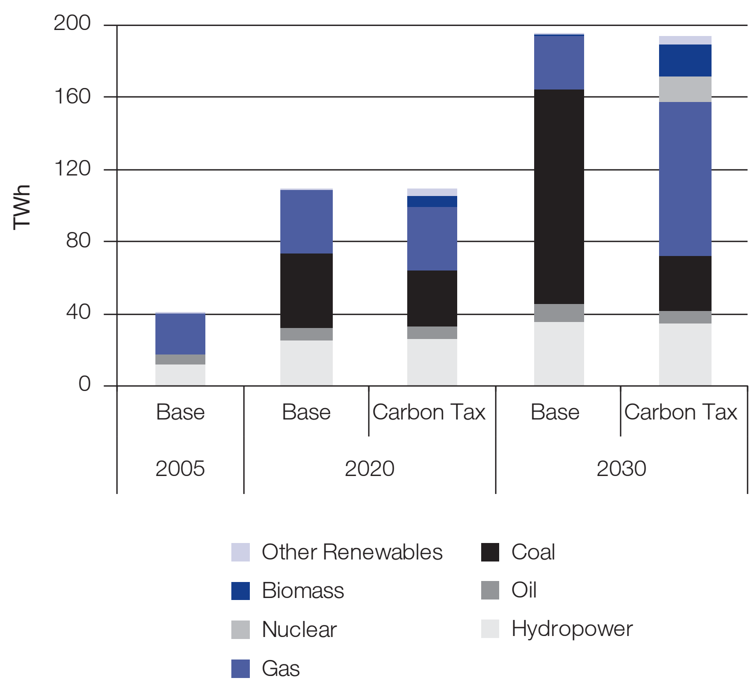
PJ = petajoule.
Source: RECCSA1 country studies (unpublished).

[20] Nuclear energy will be part of the mix in 2030 for Bangladesh.

Electricity Generation

Total power generation capacity in South Asia (excluding India) would increase from 8.45 GW in 2005 to 30.1 GW in 2030 in the base case; with the carbon tax, the total capacity in 2030 would be 3.26% higher (at about 31.1 GW) than that in the base case. The total electricity generation in South Asia in the carbon-tax scenario would be 0.2% less in 2020 and 0.8% less in 2030 than in the base case (Figure 13). The energy mix in electricity generation would significantly change with reductions in the shares of coal, oil, and hydropower, while that of natural gas, nuclear, biomass, and other renewables would increase by 2020 and 2030. Coal-based electricity generation would be reduced by 22.8% in 2020 and by 74.9% in 2030. Similarly, oil-based and hydropower electricity generation in 2030 would be reduced by around 28.5% and 1.8%, respectively, under the carbon tax. In contrast, natural gas-based electricity generation would increase to 85.7 terawatt-hours (TWh) in 2030 from 29.9 TWh in the base case. (There would also be generation of 14.4 TWh of electricity from nuclear power plants in 2030 in Bangladesh under the carbon tax.) Electricity generation based on biomass and other renewables (wind, solar, and municipal solid waste) would increase by 5.7 TWh and 3.4 TWh in 2020, respectively, and by 17.5 TWh and 3.6 TWh in 2030, respectively. Table 19 presents the estimated share in electricity generation by fuel source in South Asia under the carbon tax.

Figure 13 **Electricity Generation under Base Case and Carbon Tax in South Asia (Excluding India)**



TWh = terawatt-hour.

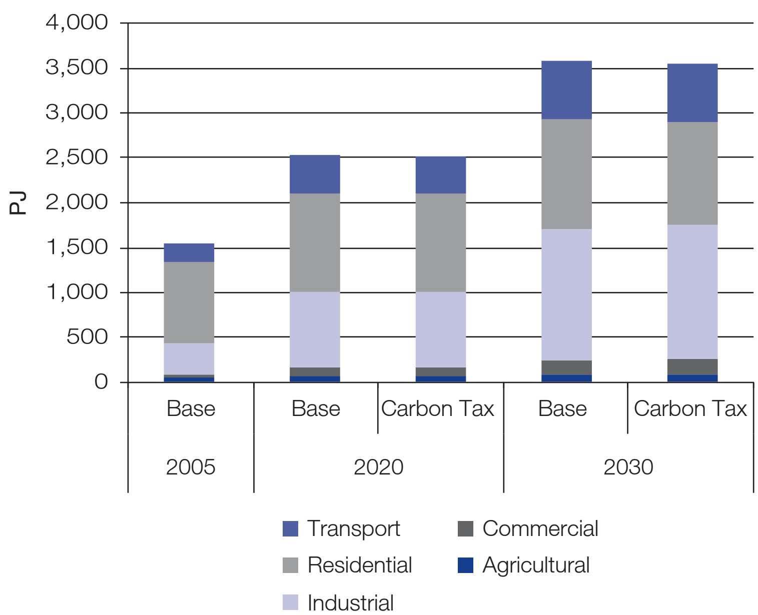
Source: RECCSA1 country studies (unpublished).

Final Energy Consumption

The base case total final energy consumption in South Asia (excluding India) would be reduced by 0.3% in 2020 and 1.0% in 2030 under the carbon tax (Figure 14). Energy consumption in the commercial sector would increase by 12.7% by 2030 from the base case, mainly influenced by Bangladesh's replacement of coal by biomass in cooking, which is less energy efficient. Similarly, energy consumption in the industrial sector is estimated to increase by 2.1% by 2030 due to increased use of biomass boilers and dryers replacing coal, fuel oil, and LPG boilers and dryers. In contrast, there would be a decrease in the energy consumption of the residential and transport sectors by 6.7% and 0.4%, respectively, by 2030.

The reduction in the residential sector is partly due to the use of more efficient air cooling devices and refrigerators and partly due to fuel switching, i.e., from agricultural residues to biogas as well as from fuelwood to LPG. The marginal decrease in the transport sector energy consumption is partly due to the use of biodiesel vessels (using biodiesel B5, containing 5% biodiesel and 95% diesel) replacing inefficient diesel vessels in the Maldives; and also due to partial replacements of light-duty gasoline and diesel vehicles by light-duty hybrid vehicles, use of electric microbuses, and partial switching from diesel to gasoline vehicles in Nepal. The region's agriculture sector is estimated to have no significant change in energy consumption under the carbon tax. Table 21 above shows the estimated sector shares in total final energy consumption by country in South Asia under the carbon tax.

Figure 14 **Final Energy Consumption under Base Case and Carbon Tax, South Asia (Excluding India)**



PJ = petajoule.

Source: RECCSA1 country studies (unpublished).

Energy-Related GHG Emissions

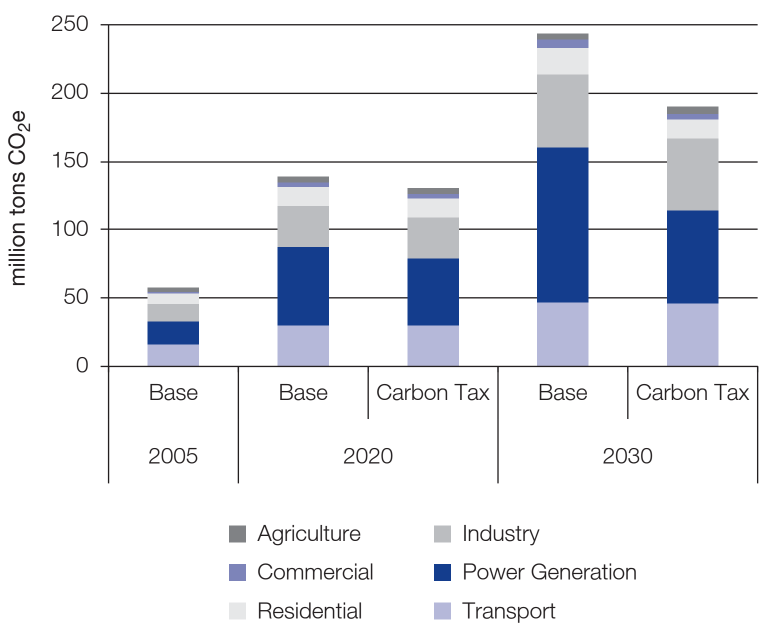
Table 22 above shows the estimated total GHG emissions of energy-using activities under the carbon tax in South Asia. The region's total annual GHG emissions would decrease by 6.1% (8.4 million t CO_2e) by 2020 and by 22.0% (53.8 million t CO_2e) by 2030 (Figure 15). There would be a cumulative reduction in GHG emission by around 971 million t CO_2e during 2005–2030 from South Asia (excluding India) as compared to the cumulative emission of 4,011 million t CO_2e in the same period in the base case.

At the country level, introducing a carbon tax would reduce Bangladesh's cumulative GHG emissions during 2005–2030 by 9.4% from the base case level, with reductions higher in later years (e.g., 20.3% reduction in 2030). In Sri Lanka, a carbon tax could cut cumulative emissions in the same period by 21.8% (186 million t CO_2e) from the base case level.

As stated earlier, some of the energy-efficient options that would be attractive under the carbon tax are already seen as cost-effective under the base case. Penetration rates applied in the study's analytical model impose upper limits on the use of clean technology options in both scenarios. Thus, in the model, clean and energy-efficient options that are already cost-effective in the base case do not offer potential for further CO_2 reduction under the carbon tax.

Power generation offers the largest potential for GHG emission reduction from South Asia (excluding India) under the carbon tax, of 14.6% (8.3 million t CO_2e) in 2020 and

Figure 15 **Sector GHG Emissions under Base Case and Carbon Tax, South Asia (Excluding India)**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: RECCSA1 country studies (unpublished).

39.9% (45.5 million t CO_2e) in 2030. The residential sector comes second, accounting for 0.2% of the total GHG reductions in 2020 and 27.4% in 2030. This is followed by the commercial sector, with shares in GHG reduction estimated at around 0.2% in 2020 and almost 22% in 2030. Meanwhile, the industry and transport sector emissions would be reduced by around 2.4% and 0.8%, respectively. No significant reduction in GHG has emerged from the agricultural sector under the carbon tax.

Emission of Local/Regional Pollutants

There would be a significant reduction in sulfur dioxide (SO_2) emission from South Asia (excluding India) under the carbon tax: 5.4% lower in 2020 and 37.1% lower in 2030 than the corresponding levels in the base case (Table 23). While nitrogen oxides (NO_x) emissions from South Asia (excluding India) would be slightly lower (0.3%) in 2020 under the carbon tax, they would be higher by 3.0% by 2030 from the base case level.

Table 23 **Local Pollutant Emission Reduction under the Base Case and Carbon Tax, South Asia (Excluding India), 2020 and 2030** ('000 tons)

Local Pollutants	2020 Base Case	2020 Carbon Tax	2020 % Change in 2020*	2030 Base Case	2030 Carbon Tax	2030 % Change in 2030
NO_X	1,209	1,205	0.3	1,950	2,010	(3.0)
SO_2	374	353	5.4	678	426	37.1

( ) = negative, NO_X = nitrogen oxides, SO_2 = sulfur dioxide.

Note: A positive % change means a reduction in emission, while a negative % change means an increase in emission.

Source: RECCSA1 country studies (unpublished).

Cost Implications

The present study finds that under the carbon tax, the total discounted energy system cost[21] of South Asia (excluding India) would increase only by 0.4% ($1,408 million at constant 2005 prices) during 2005–2030, whereas the discounted total investment cost would increase only by 0.3% ($895 million) from the base case level. However, the proportion of fixed and variable operation and maintenance costs in the total energy system cost would increase from 28.9% in the base case to about 32.2% in the carbon tax. With a carbon tax, the total investment required for power generation in South Asia (excluding India) during 2005–2030 is estimated at $105 billion (in nominal terms) as compared to $103 billion in the base case.

It should be noted that in this analysis, the increase in the total energy system cost includes the "carbon tax revenue" of $19,453 million generated under the carbon tax,[22] and that the carbon tax revenue is not "recycled" (i.e., not used to subsidize cleaner technology options).

[21] The total discounted energy system cost includes the cost of technology investment, and fixed and variable operation and maintenance cost.

[22] More accurately, the "carbon revenue" in the present modeling context refers to the carbon tax revenue. Carbon tax is used as a proxy for carbon price here. It is also assumed that the carbon prices as assumed in the study under the carbon-tax scenario will be prevalent in the international carbon market.

Table 24 **Total GHG Emissions at Selected Incremental Abatement Costs in 2020, South Asia (Excluding India)**

Incremental Abatement Cost ($ per ton CO_2e)	Total GHG Emissions ('000 ton CO_2e)	% GHG Emissions Reduction from Base Case Level	Incremental Abatement Cost ($ per ton CO_2e)	Total GHG Emissions ('000 ton CO_2e)	% GHG Emissions Reduction from Base Case Level
< 0 ("No-regret" options)	125,676	9.58	100	107,282	22.82
10	111,126	20.06	200	107,015	23.02
30	108,559	21.90	300	107,009	23.02
50	107,676	22.54	400	106,313	23.52
75	107,587	22.60	~500	106,245	23.57

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Note: Base case total GHG emission level = 138.999 million t CO_2e. In this table, total GHG emission at a particular value of incremental abatement cost (IAC) represents the level of GHG emission that would take place when all the options with IAC less than or equal to the particular value are deployed.

Source: Authors' calculations.

GHG Abatement Potential and Costs

This study conducted the GHG abatement cost analysis with a limited number of national abatement options for Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka for 2020. The analysis shows a significant potential for GHG mitigation (or emission reduction) at negative and low abatement costs (Table 24). More specifically, total GHG emissions decrease and percentage reductions from the base case emission level increase, with increasing per-unit incremental abatement cost (IAC).

Across the five countries, there is a potential emission reduction of about 13.3 million t CO_2e (about 9.6% of the base case emissions) in 2020 at no additional cost by deploying several "no-regret" types of clean and energy-efficient options. An IAC of $10 and $50 per ton of CO_2e could reduce emissions by about 20.1% and 21.9% in 2020, respectively.

Using the "no-regret" options, the residential sector offers the highest potential (49.8%) for mitigating energy-related GHG emissions, followed by the transport and industry sectors (Table 25). Across the different (increasing) levels of IACs, the power sector accounts for the largest share in total GHG reduction, followed by the residential, industry, transport, commercial, and agriculture sectors (in this order). However, perhaps due to the limited number of GHG abatement options considered in this study, there is no significant increase in total abatement potential at IACs above $50 per ton of CO_2e. As such, the GHG abatement potentials at different IACs are most likely to be underestimated in the present analysis.

The matrix summarizes the "no-regret" options identified for each country from among the limited clean technologies and resources considered in the study.

While some of the clean technology and resource options are cost-effective in the base case, their adoption levels were restricted through penetration rates (which have been

Country	Potential “No-regret” Options
Bangladesh	Efficient lamps, i.e., compact fluorescent lamps (CFLs) in the residential sector; energy efficient boilers, brick kilns, rice parboiling and milling in the industry sector; efficient irrigation pumps in the agriculture sector; fuel switching of car transport demand to compressed natural gas (CNG) (95%) and gasohol (5%), efficient passenger and freight water transport system, partial modal shift in the road freight demand to railways in the transport sector
Bhutan	Use of electric cooking to replace LPG and kerosene based cooking in the residential and commercial sectors; increasing the share of electric buses, and replacing light diesel vehicles by light electric vehicles
The Maldives	Solar cooking stoves to replace 10% of kerosene cooking stoves in the residential sector; use of municipal solid waste to replace 50% of diesel-based power generation in Thilafushi Island
Nepal	Improved fuelwood cooking stoves, electric cookers, and electric water heaters in the residential and commercial sectors; use of efficient diesel boilers replacing conventional boilers in the industrial sector
Sri Lanka	Efficient refrigerators and CFLs in the residential sector; efficient air conditioners in the residential and commercial sectors; energy-efficient electric motors and advanced fuel oil boilers in the industrial sector; efficient diesel tractors and biodiesel fishing boats in the agriculture sector; adoption of efficient heavy diesel trucks and diesel buses in the transport sector

Table 25 **Sector Shares in Total GHG Emission Abatement at Selected Incremental Abatement Costs, South Asia (Excluding India)** (%)

	Incremental Abatement Cost (\$ per ton CO_2e)									
Sector	≤ **0** (“No-regret” Options)	**10**	**30**	**50**	**75**	**100**	**200**	**300**	**400**	**~500**
Residential	49.8	24.0	25.3	24.6	24.8	24.6	24.5	24.5	25.9	25.9
Commercial	1.5	2.2	2.2	2.1	2.1	2.1	2.4	2.7	2.6	2.6
Transport	25.0	12.2	11.2	13.0	13.0	13.0	13.1	13.1	13.0	13.0
Industry	22.4	24.5	22.4	22.5	22.4	22.3	22.1	22.0	21.6	21.7
Agriculture	1.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
Power (electricity) generation	0.0	36.5	38.3	37.2	37.1	37.5	37.3	37.2	36.4	36.3

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.
Source: Authors’ calculations.

imposed on the analytical models) to reflect possible barriers, user preferences, and other constraints. The limits on adoption level of the cost-effective cleaner options have been relaxed to some extent; hence, the options appear as “no-regret” options in the abatement cost analysis.

In the case of India, a study of abatement options in the 10 largest energy consuming and emitting sectors in 2030 shows that acceleration of different programs for energy efficiency and clean power infrastructure would substantially reduce carbon emissions in the country (McKinsey and Company 2009). The programs include investments in new technologies, such as LED technology, supercritical and ultrasupercritical[23] power plants, efficient transport infrastructure, and a widespread improvement in agricultural practices. The study shows that energy-efficient equipment and appliances and mileage standards would jointly abate around 120 million t CO_2e in 2030 at negative costs (i.e., <0 euro/ton). LED lighting would reduce around 35 million t, and efficient cooking stoves 20 million t, of CO_2e in 2030 at negative abatement cost. Similarly, an introduction of supercritical coal technology would, at a modest cost of up to $25 per ton, abate around 200 million t CO_2e in 2030. While large-scale adoption of nuclear energy is challenging, the study also shows that an addition of 30–60 GW of nuclear power would abate around 250 million t CO_2e in 2030, at an abatement cost of up to $25 per ton. Above this abatement cost, public bus-based transport systems would be attractive and would abate around 20 million t CO_2e in 2030.

Activities Not Using Energy[24]

This section presents the analyses of GHG emissions generated during 2005–2030 from activities not using energy (hereafter called "the non-energy sector") in Bangladesh, Bhutan, Nepal, and Sri Lanka, as well as those of India, which were estimated following the Mitra and Bhattacharya (2002) approach.[25] The analysis considers CO_2, methane (CH_4), and nitrous oxide (N_2O), and covers four subsectors (agriculture,[26] forestry, waste generation, and industrial processes). The costs and GHG abatement potential of major options in 2020 are also discussed.

Given the large degree of similarity across countries in methodological approach and the nature of abatement options examined in each sector, this section highlights the results by sector; country results are presented under each sector assessment. It is important to note however that none of the options examined to abate GHG emissions in the non-energy sector are of a "no-regret" nature.

GHG emissions from agriculture and industrial processes until 2030 were estimated using the average annual growth rates of activity (subsector) data (e.g., livestock population, area under rice cultivation, crop production, fertilizer consumption, ammonia production, cement production, metal production, etc.). Emission factors based on the 1996 IPCC

[23] Supercritical and ultrasupercritical power plants operate at temperatures and pressures above the critical point of water, i.e., above the temperature and pressure at which the liquid and gas phases of water co-exist in equilibrium, at which point there is no difference between water gas and liquid water. This results in higher efficiencies—above 45%. Supercritical and ultrasupercritical power plants require less coal per megawatt-hour, leading to lower emissions (including carbon dioxide and mercury), higher efficiency, and lower fuel costs per megawatt (Source: http://www.greenfacts.org/glossary/pqrs/supercritical-ultra-supercritical-technology.htm).

[24] This section is based on four country level modeling studies and reports co-authored and led by Rodel Lasco. These national reports contain considerably more detailed and technical information than presented in this regional synthesis report. The national reports are available on request.

[25] The Maldives has no significant "non-energy sector" and hence was not included in this aspect of the regional study.

[26] The agriculture sector is further subdivided into livestock raising and crop production (rice cultivation, field burning of agricultural residue, and agricultural soils). The GHG emissions from livestock raising can be categorized into two major activities, enteric fermentation and manure management. The livestock types considered here include cattle, buffalo, goat, sheep, swine, and poultry. Yaks and horses were also included in the analysis for Bhutan.

guidelines were applied to the activity levels (actual and projected) to derive the emission projections per subsector. GHG emissions are expressed in terms of CO_2e using the global warming potential values based on a 100-year time horizon, as given in the 2007 IPCC Fourth Assessment Report. It is against these projections that the impacts and costs of GHG emissions reduction options are assessed.

Land use, land-use change, and forestry activities, mainly tropical deforestation, are significant net sources of CO_2, accounting for 1.6 gigatons carbon per year of anthropogenic emissions. However, tropical forests also have the largest potential among the world's forests to mitigate climate change through conservation of existing carbon pools (e.g., reduced impact logging), expansion of carbon sinks (e.g., reforestation, agroforestry), and substitution of wood products for fossil fuels (Brown et al. 1996). Reducing deforestation is thus a high-priority abatement option in tropical regions, which could provide significant carbon gains and substantive environmental and other benefits. For the forestry sector, data on type of forest, forest area, deforestation rate, and reforestation/plantation rate were used to estimate GHG emissions/absorption in the base case.[27]

Globally, landfills and open dumps are the dominant waste management and disposal methods, which lead to anaerobic degradation of organic material and CH_4 emissions. IPCC business-as-usual projections for 2005–2020 indicate that landfills will remain the largest source of CH_4 at 55%–60% of the total. In this study, the GHG emissions from the waste generation sector during 2005–2030 were calculated based on urban population data, municipal solid waste (MSW) generated per capita per day, fraction of MSW disposed to solid waste disposal sites, and fraction of degradable organic component in MSW.

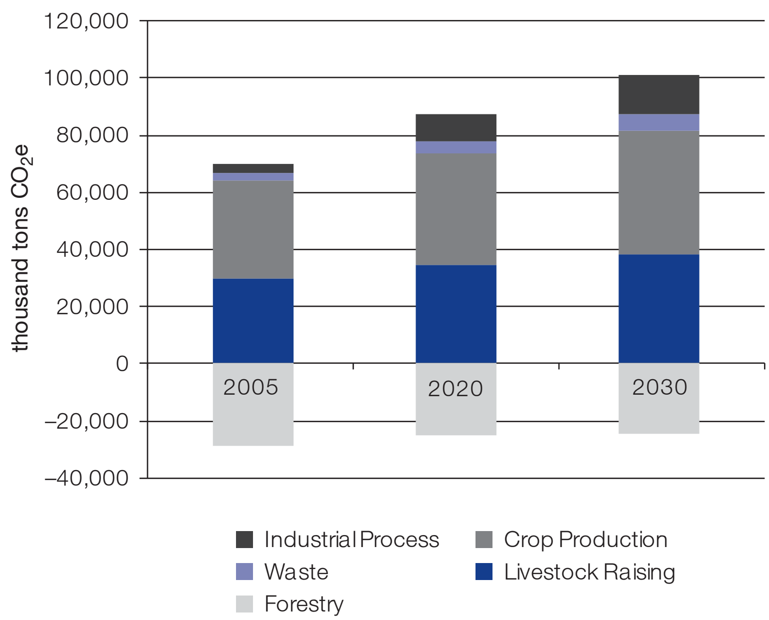
For the industrial processes sector, cement production has as end-products lime or calcium oxide and CO_2. This study focused on the cement industry in South Asia, given that it is the most important source of industrial GHG emissions and is common to Bangladesh, Bhutan, Nepal, and Sri Lanka.

Base Case GHG Emissions in 2005–2030

The net GHG emissions from the non-energy sectors of the four South Asian countries combined have been estimated to increase at a CAGR of 2.5% from 40.5 million t CO_2e in 2005 to 76 million t CO_2e in 2030 (Figure 16). In 2005, the total GHG emission from the non-energy sectors across the four countries was 69.8 million t CO_2e, while the forestry sector had sequestered 29.3 million t CO_2e. Most of the total GHG emissions came from crop production, followed by livestock raising, industrial processes, and waste (Figure 17). By 2030, the total GHG emission from the non-energy sectors would be about 101 million t CO_2e, while the forestry sector would sequester around 24.9 million t CO_2e. Table 26 shows the estimated base case GHG emissions in 2005 and 2030 by activities not using energy in South Asia.

[27] For this study, local experts in Bhutan have determined that because of its steep terrain and topography, forest regeneration may not be a suitable option in Bhutan (or may be prohibitively costly). For this reason, the forestry sector was not included in the analysis for Bhutan.

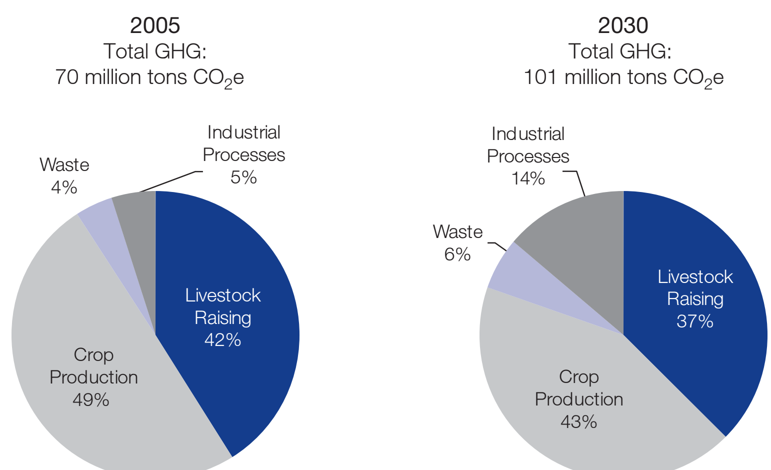
Figure 16 **Total GHG Emissions from Activities Not Using Energy, South Asia (Excluding India and the Maldives), 2005–2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: RECCSA1 country studies (unpublished).

Figure 17 **Sector Share in Total GHG Emissions from Activities Not Using Energy (Except Forestry), South Asia (Excluding India and the Maldives), 2005 and 2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: RECCSA1 country studies (unpublished).

Table 26 **Base Case Total GHG Emissions from Activities Not Using Energy, South Asia, 2005 and 2030** (million tons CO_2e)

	Crop Production	Livestock Raising	Forestry	Industrial Processes	Waste Generation	Total
Bangladesh						
2005	25.86	19.19	(1.34)	2.33	2.04	48.08
2020	29.25	21.05	(1.25)	5.27	3.64	57.96
2030	32.00	22.62	(1.19)	5.53	5.07	64.03
Bhutan						
2005	0.08	0.29	(12.68)	0.28	0.06	(11.97)
2020	0.11	0.54	(13.77)	1.38	0.08	(11.66)
2030	0.15	0.83	(15.44)	2.36	0.09	(12.02)
India						
2005	314.9	213.8	–	–	103.1	631.8
2020*	517.7	242.6	–	–	296.7	1,057.0
2030	730.7	264.0	–	–	600.2	1,594.9
Nepal						
2005	4.72	8.84	(18.78)	0.17	0.09	(4.95)
2020	5.68	10.94	(16.61)	0.86	0.13	1.00
2030	6.43	12.83	(15.81)	1.14	0.15	4.74
Sri Lanka						
2005	3.49	1.34	3.50	0.47	0.57	9.37
2020	4.19	1.45	6.02	2.05	0.59	14.3
2030	4.74	1.54	7.51	4.89	0.59	19.27
South Asia (including India)						
2005	349.05	243.46	(29.30)	3.25	105.86	672.33
2020	556.96	276.56	(25.60)	9.56	301.14	1,118.62
2030	774.02	301.82	(24.93)	13.92	606.10	1,671.02
South Asia (excluding India)						
2005	34.15	29.66	(29.30)	3.25	2.76	40.53
2020	39.24	33.98	25.60	9.56	4.43	61.60
2030	43.32	37.82	(24.93)	13.92	5.90	76.02

– = no analysis, ( ) = negative, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

* For India, total figure in 2020 came from Mitra and Battacharya (2002).

Notes:

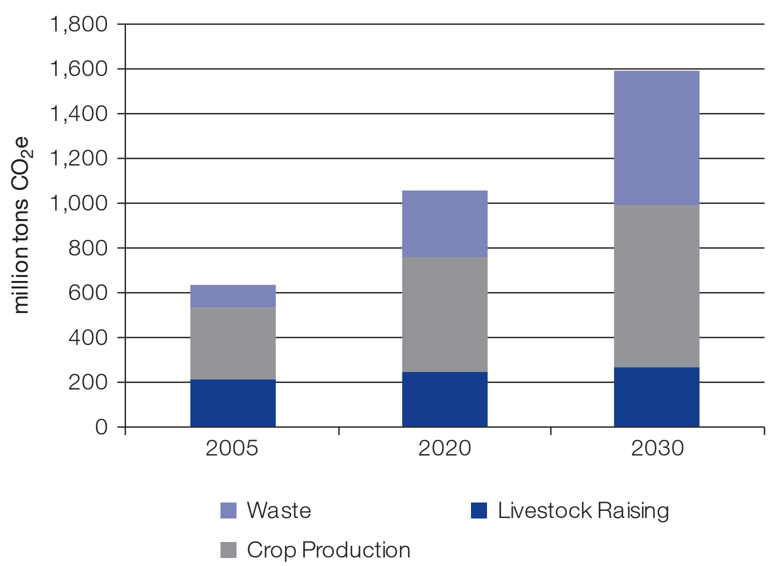
1. GHG emission from crop production refers to those from rice cultivation, field burning of agricultural residues, and agricultural soils.
2. Livestock raising refers to that of cattle, buffalo, goat, sheep, swine, and poultry. GHG emissions from this sector are those from enteric fermentation and manure management.

Source: RECCSA1 country studies (unpublished).

For India, the GHG emissions from livestock raising, crop production, and waste disposal were estimated to grow from 632 million t in 2005 to 1,057 million t in 2020 and 1,595 million t in 2030 (Mitra and Bhattacharya 2002; GoI MoEF 2009; Figure 18).[28]

According to India's First National Communication to UNFCCC, the forestry sector's CO_2 emission in 1994 was 37.7 million t while its CO_2 removal (sequestration) was 23.4 million t (GoI MoEF 2004). The Second National Communication of India states that there was a CO_2 removal of 236.3 million t in 2000 (GoI MoEF 2012). These two official documents also stated that India's industrial processes sector emitted around 99.9 million t CO_2 in 1994 and 72.6 million t CO_2 in 2000. Figure 19 presents the sector shares in India's total GHG emissions from the livestock, crop production, and waste subsectors; crop production has the largest contribution to total GHG emissions.

Figure 18 **Total GHG Emissions from Activities Not Using Energy (Excluding Forestry and Industrial Processes), India, 2005–2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

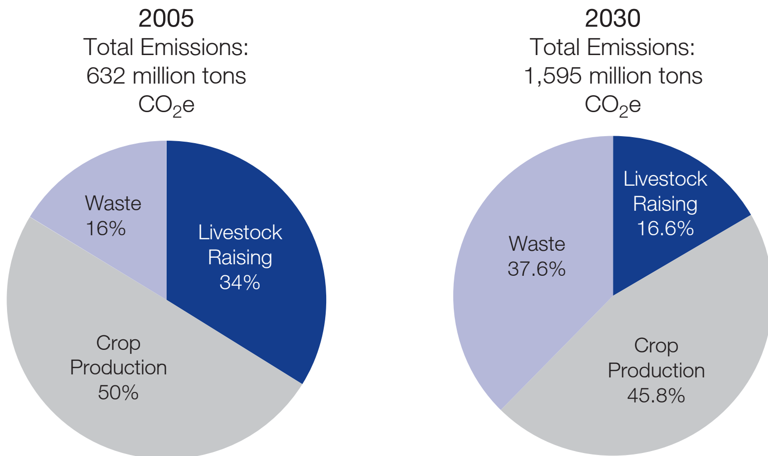
Sources:

Mitra, A.P. and S. Bhattacharya. 2002. Climate Change and Greenhouse Gas Inventories: Projections, Impacts and Mitigation Strategies. In P.R. Shukla et al., eds. *Climate Change and India: Issues, Concerns and Opportunities*. Tata McGraw-Hill Publishing Company Limited. New Delhi.

GoI MoEF (Government of India, Ministry of Environment and Forest). 2009. *India's GHG Emissions Profile, Results of Five Climate Modeling Studies*. New Delhi.

[28] From Mitra and Bhattacharya (2002), the 1994–2000 CAGRs used for these projections are as follows: CH_4 emissions from livestock enteric fermentation, 0.9%; manure management, 0.4%; rice cultivation, 3.0%; and field burning of agricultural residues, 6.8%. CO_2 emissions from cement production, 16.4%, and forestry sector, 52.0%. N_2O emissions from nitric acid production, 50.2%, soils, 2.4%; and crop residue burning, 4.9%. The 2005–2020 projections came from Mitra and Bhattacharya (2002), and the current study derived the 2030 projections. In addition, Mitra and Bhattacharya (2002) used the 1994–2000 CAGR of 4.4% to estimate waste generation until 2025, while the current study used a 1994–2007 CAGR of 7.3% (GoI MoEF 2009) to estimate India's waste-related emissions up to 2030.

Figure 19 **Sector Share in Total GHG Emissions from Activities Not Using Energy (Excluding Forestry and Industrial Processes), India, 2005 and 2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Mitra, A.P. and S. Bhattacharya. 2002. Climate Change and Greenhouse Gas Inventories: Projections, Impacts and Mitigation Strategies. In P.R. Shukla et al., eds. *Climate Change and India: Issues, Concerns and Opportunities*. Tata McGraw-Hill Publishing Company Limited. New Delhi.

The non-energy related GHG emissions from agriculture, forestry, waste, and industrial processes are discussed on the following pages.

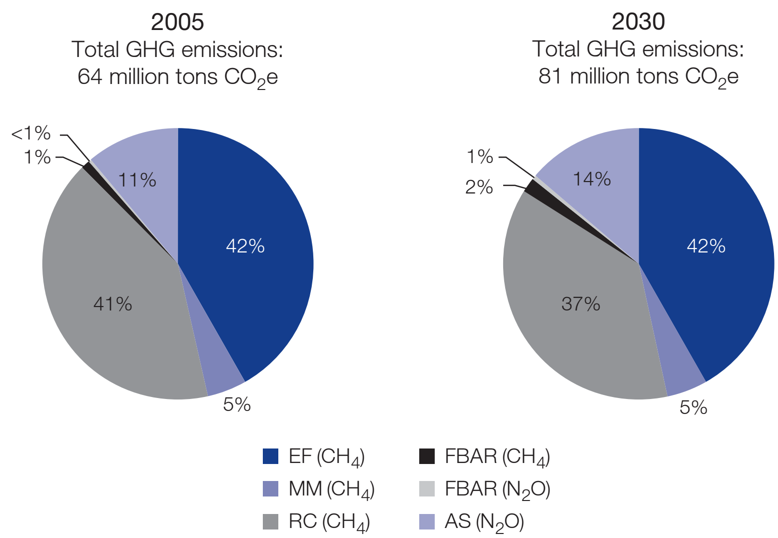
Agriculture

The combined total non-energy related GHG emissions from the agriculture sector of South Asia (excluding India and the Maldives) were 64 million t CO_2e in 2005 and would reach 81 million t CO_2e in 2030 at about 1.0% CAGR. The corresponding figures for India are estimated to be 529 million t in 2005 and 995 million t in 2030. Crop production and livestock raising accounted for about 54% and 46%, respectively, of the total agriculture-related emissions in the region in 2005 (Figure 20). Among these activities, rice cultivation is estimated to contribute the most (37.4%) to GHG emissions in 2030, followed by enteric fermentation, agricultural soils, manure management, and field burning of agricultural residues (in this order). Including India with the four countries above, livestock raising contributed the most (41.1%) to the agriculture sector's GHG emissions in 2005; its share is estimated to decrease to 28.1% in 2030 (Figure 21). In 2030, rice cultivation would have the largest share in the sector's GHG emission from these five South Asian countries.

Enteric fermentation accounts for about 90% of total GHG emissions from livestock in South Asia (excluding India and the Maldives) during 2005–2030, with the rest coming from manure management (Figure 22). This is also the case when livestock emissions from India are included with those of the four countries (Figure 23).

Across South Asia (excluding India and the Maldives), methane emissions from rice cultivation are predominant in the total GHG emissions from crop production-related

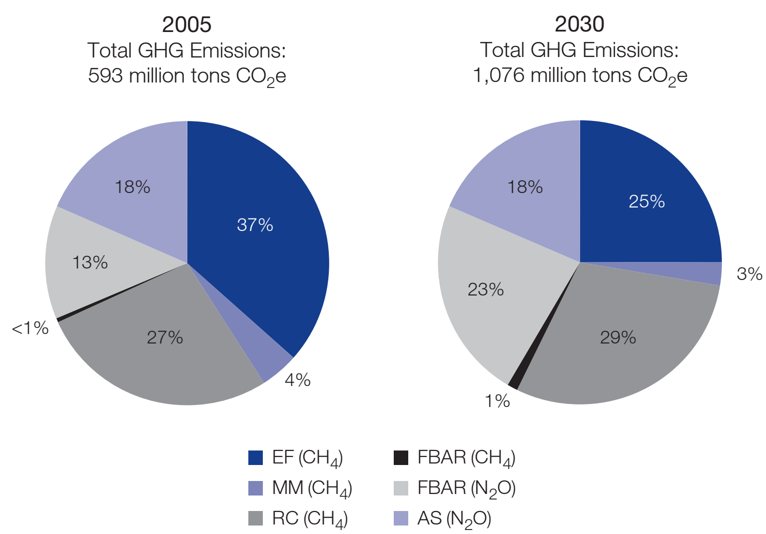
Figure 20 Share in Total GHG Emissions of Agricultural Activities, South Asia (Excluding India and the Maldives), 2005 and 2030



AS = agricultural soils, CH_4 = methane, CO_2e = carbon dioxide equivalent, EF = enteric fermentation, FBAR = field burning of agricultural residue, GHG = greenhouse gas, MM = manure management, N_2O = nitrous oxide, RC = rice cultivation.

Source: RECCSA1 country studies (unpublished).

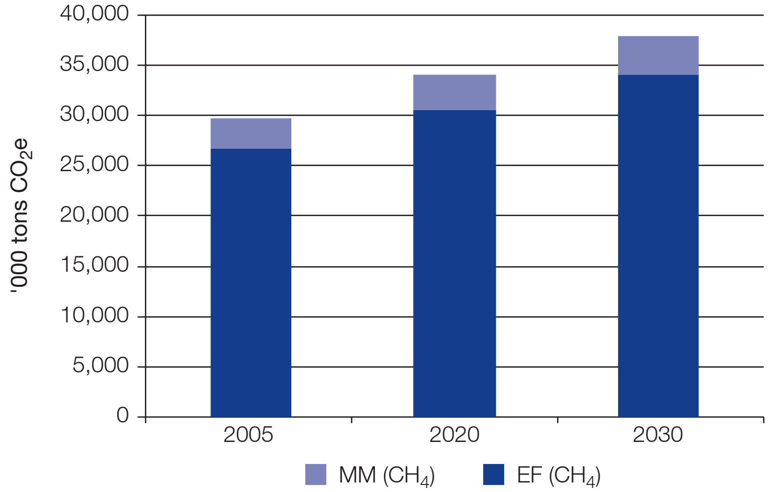
Figure 21 Shares in Total GHG Emissions of Agricultural Activities, South Asia (Excluding the Maldives), 2005 and 2030



AS = agricultural soils, CH_4 = methane, CO_2e = carbon dioxide equivalent, EF = enteric fermentation, FBAR = field burning of agricultural residue, GHG = greenhouse gas, MM = manure management, N_2O = nitrous oxide, RC = rice cultivation.

Source: RECCSA1 country studies (unpublished).

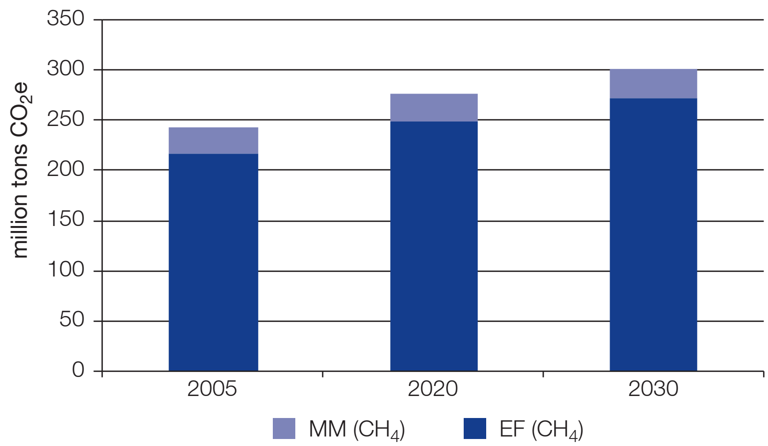
Figure 22 **GHG Emissions from Livestock Raising, South Asia (Excluding India and the Maldives), 2005–2030**



CH_4 = methane, CO_2e = carbon dioxide equivalent, EF= enteric fermentation, GHG = greenhouse gas, MM = manure management.

Source: RECCSA1 country studies (unpublished).

Figure 23 **GHG Emissions from Livestock Raising, South Asia (Excluding the Maldives), 2005–2030**

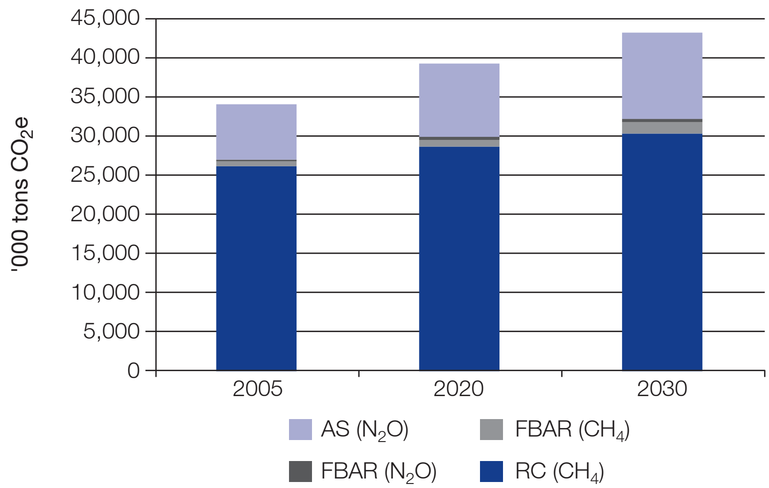


CH_4 = methane, CO_2e = carbon dioxide equivalent, EF= enteric fermentation, GHG = greenhouse gas, MM = manure management.

Source: RECCSA1 country studies (unpublished).

activities, although their share is estimated to decrease from 76.8% in 2005 to 70.1% in 2030 (Figure 24). N_2O-emitting agricultural soil is the second largest contributor with a share estimated to increase from around 20.7% in 2005 to 25.7% in 2030. The share of field burning of agricultural residues in the total GHG emissions from crop production is estimated to increase from about 2.5% in 2005 to 4.3% in 2030.

Figure 24 **GHG Emissions from Crop Production-Related Activities, South Asia (Excluding India and the Maldives), 2005–2030**



AS = agricultural soils, CH_4 = methane, CO_2e = carbon dioxide equivalent, FBAR = field burning of agricultural residue, N_2O = nitrous oxide, RC = rice cultivation.

Source: RECCSA1 country studies (unpublished).

Including India with the four countries, methane emissions from rice cultivation have the largest share in total GHG emissions from crop production during 2005–2030 (Figure 25). It is followed by agricultural soils as the second largest emitter in 2005, while field burning of agricultural residues occupies this place in 2030.

Forestry

The baseline projection of GHG emissions from the forestry sector used the 2000–2005 historical deforestation and plantation rates of Bangladesh, Bhutan, Nepal, and Sri Lanka. The total area under forest cover in these countries was around 10.0%, 72.5%, 40.0%, and 31.0%, respectively (FAO 2001; FAO 2005; GPRB BBS 2010).

Their total GHG removal capacity was 29 million t CO_2e in 2005, but estimated to decline to 26 million t CO_2e in 2020 and 25 million t CO_2e in 2030 (Figure 26). This projected trend is due to the increasing deforestation rates in Nepal and Bangladesh, reported to be at 27,000 hectares/year[29] and 3,000 hectares/year,[30] respectively, during 2005–2010.

Waste Disposal

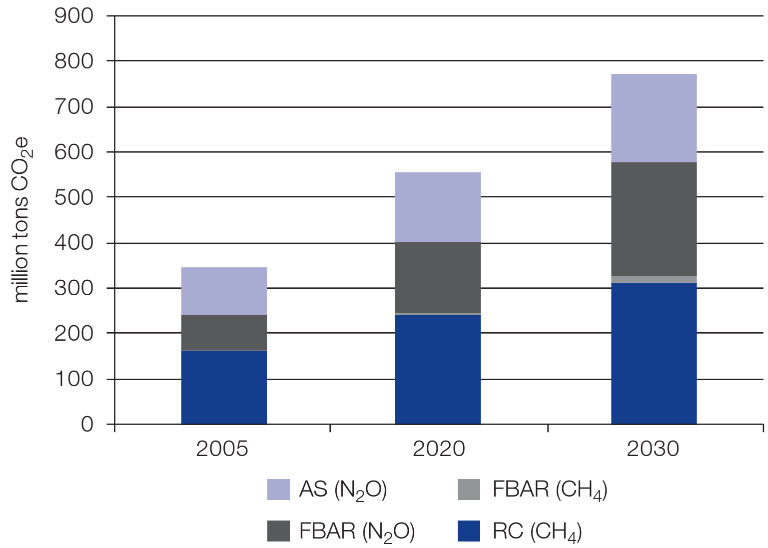
The rapid urbanization widely taking place in South Asia presents a growing problem associated with solid waste disposal. Total GHG emission from waste generation in the four countries is estimated to be 2.7 million t CO_2e in 2005 and projected to reach 5.9 million t CO_2e in 2030 (Figure 27). Including India, the total GHG emission from waste generation is estimated to be 106 million t CO_2e in 2005 and 606 million t CO_2e in 2030[31] (Figure 28).

[29] Source: http://rainforests.mongabay.com/deforestation/2000/Nepal.htm

[30] Source: http://rainforests.mongabay.com/deforestation/2000/Bangladesh.htm

[31] For India, the 2005 estimated value is based on GoI MoEF (2009), while that for 2030 was estimated using the 1994–2007 CAGR given also in GoI MoEF (2009).

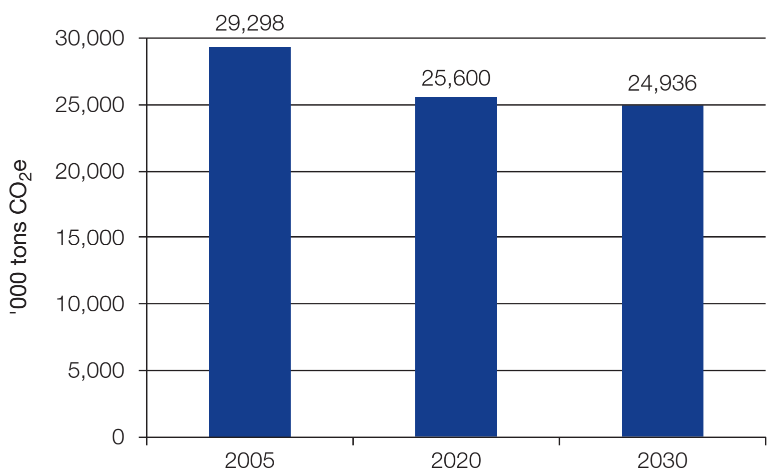
Figure 25 **GHG Emissions from Crop Production-Related Activities, South Asia (Excluding the Maldives), 2005–2030**



AS = agricultural soils, CH_4 = methane, CO_2e = carbon dioxide equivalent, FBAR = field burning of agricultural residue, GHG = greenhouse gas, N_2O = nitrous oxide, RC = rice cultivation.

Source: RECCSA1 country studies (unpublished).

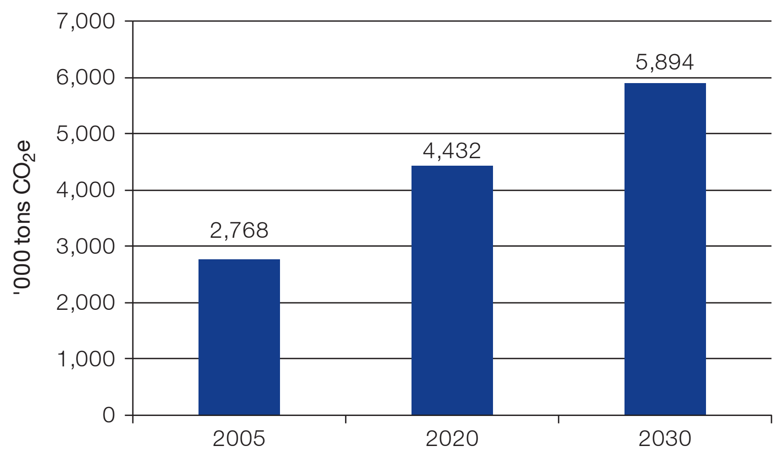
Figure 26 **Greenhouse Gas Sink Capacity of the Forestry Sector, South Asia (Excluding India and the Maldives), 2005–2030**



CO_2e = carbon dioxide equivalent.

Source: RECCSA1 country studies (unpublished).

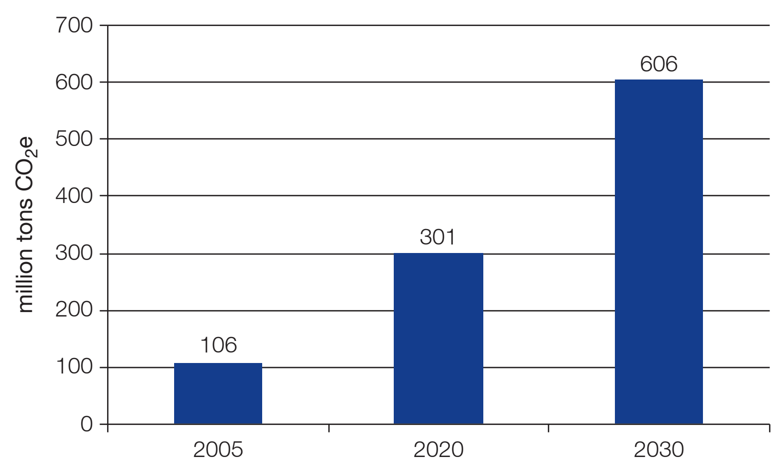
Figure 27 **Greenhouse Gas Emissions from the Waste Disposal Sector, South Asia (Excluding India and the Maldives), 2005–2030**



CO_2e = carbon dioxide equivalent.

Source: RECCSA1 country studies (unpublished).

Figure 28 **Greenhouse Gas Emissions from the Waste Disposal Sector, South Asia (Excluding the Maldives), 2005–2030**



CO_2e = carbon dioxide equivalent.

Source: RECCSA1 country studies (unpublished).

Industrial Processes

The main sources of GHG emissions from industrial processes in South Asia are industries producing ammonia, cement/clinker, iron and steel, limestone and dolomite, soda ash, calcium carbide, and ferrosilicon. Within this group, cement/clinker production and ammonia production are the most important sources of CO_2 emissions in the region.

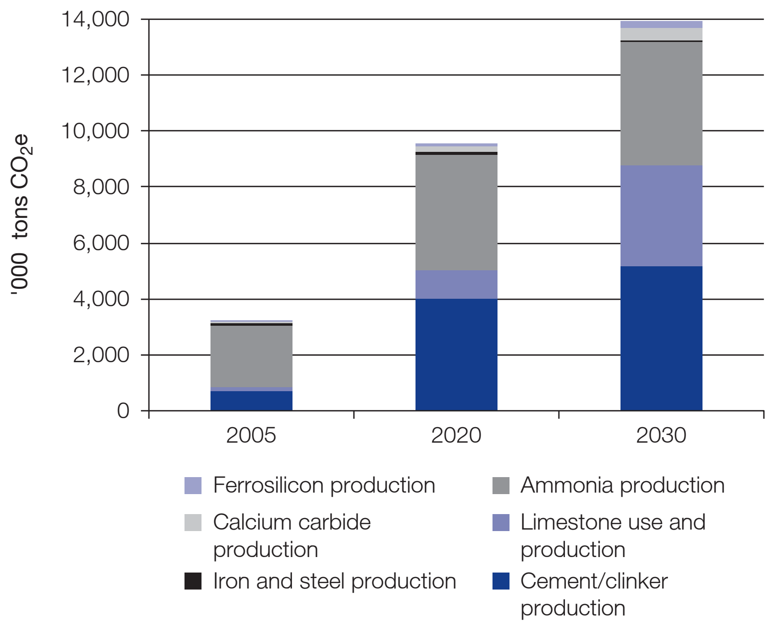
Excluding India and the Maldives, the total CO_2 emission from industrial processes in South Asia was estimated to be 3.2 million t in 2005, increasing to 9.6 million t in 2020 and to 13.9 million t in 2030 (Figure 29). Ammonia production contributed the largest share (68%) in 2005. By 2030, cement/clinker production is estimated to have the largest share (37%) (Figure 30).

Cleaner Energy Options, GHG Abatement Potential, and Costs in 2020

Based on the business-as-usual emission projections, the priority abatement options for each of the activities not using energy were identified and examined for Bangladesh, Bhutan, Nepal, and Sri Lanka. Table 27 summarizes these abatement options, and their respective estimated GHG emission abatement potential and per-ton CO_2e incremental abatement cost (IAC) in 2020 for these four countries.[32] The country-specific GHG abatement potentials and IACs are presented in Appendixes 1 and 2.

Across the four subsectors not using energy considered in this study, forestry ranks first in terms of GHG abatement potential for the year 2020, at about 23.56 million t

Figure 29 **Greenhouse Gas Emissions from Industrial Processes, South Asia (Excluding India and the Maldives), 2005–2030**

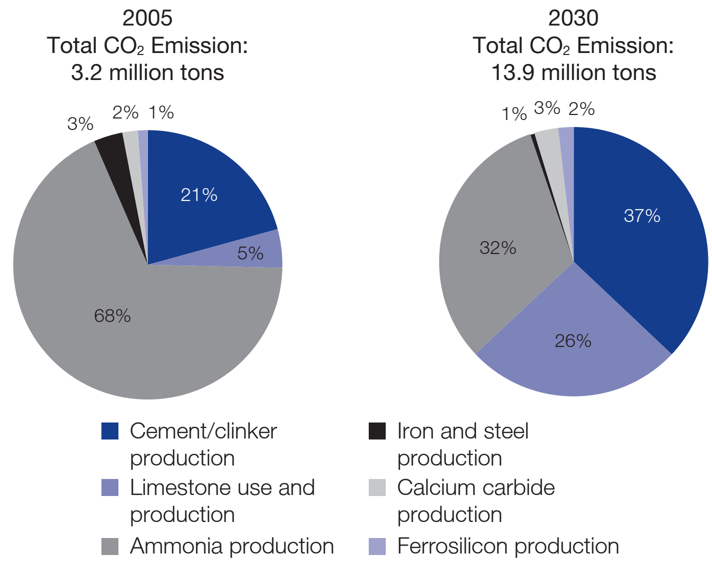


CO_2e = carbon dioxide equivalent.

Source: RECCSA1 country studies (unpublished).

[32] Not all GHG emissions abatement technologies have been assessed in each country study. For example, improvement of grazing management combined with supplement blocks may offer significant opportunity for GHG abatement through soil carbon sequestration (under pasture lands) and reduced emissions from livestock through improved livestock productivity, digestion, and reduced stock numbers. In addition, reduced or minimum tillage agriculture reduces emissions during land preparation and improves soil carbon capture. Livestock manure is also a significant source of methane, which can be captured for energy production. The adoption of urea briquette technology allows reduced urea fertilizer rates and/or improved fertilizer uptake, thus reducing GHG emissions.

Figure 30 Subsector Shares in Industrial Process-Related Greenhouse Gas Emissions, South Asia (Excluding India and the Maldives), 2005 and 2030



Source: RECCSA1 country studies (unpublished).

CO_2e, followed by industrial processes, waste disposal/management, and agriculture (in this order). However, the waste management subsector posted the lowest marginal abatement costs per ton CO_2e abated (with recycling and composting), while industrial processes posted the highest per-ton IACs. The results by sector are discussed below.

Agriculture

Increasing livestock productivity lowers emissions per animal and per unit product (De Haan, Steinfeld, and Blackburn 1996). Adding urea to the diet of ruminants, and urea treatment of crop residues prior to feeding to local dairy cattle, both help improve the digestive efficiency of livestock and reduce their GHG emissions. Supplementing ruminant diets with urea-molasses multi-treatment blocks (UMMB) has been done in Bangladesh, India, and Pakistan, and showed GHG emission reductions by as much as 35%. Aside from this benefit, UMMB and urea-treated straw (UTS) feeding were found to increase milk production by as much as 25% and 30%, respectively. For crop production, midseason drainage and intermittent irrigation can reduce methane emissions in flooded ricefields by more than 40% (Wassman, Hosen, and Sumfleth 2009).

Across these four agriculture-related technologies, the total GHG abatement potential in 2020 comes to around 1.37 million t CO_2e in South Asia (excluding India and the Maldives), while the cumulative total during 2005–2030 is about 33.1 million t CO_2e. The sector's total GHG abatement potential in 2020 could range from 60,258 t CO_2e (using urea-treated straw) to 933,120 t CO_2e (with multiple aerated rice production). The range of IAC per ton CO_2e would be \$3.01–\$25.03 (for multiple aerated rice production) and \$43.66–\$45.99 (for urea-treated straw) (Table 27).

Table 27 **Total GHG Abatement Potential and Costs from Activities Not Using Energy, South Asia (Excluding India and the Maldives), 2020**

Sector/Abatement Option	Assumptions Related to the Abatement Option Used in this Study	GHG Abatement Potential (ton CO_2e)		Incremental Abatement Cost in 2020 (\$/ton CO_2e)[b]
		2020	Total 2005–2030[a]	
Agriculture	*Subtotal*	*1,369,565*	*33,054,485*	
1. Urea-molasses multi-nutrient blocks (UMMB)	10% of improved dairy cattle can be targeted for UMMB supplementation starting in 2006. The targeted number can be increased annually at the GDP growth rate until 2030 to simulate increasing coverage over time.	101,145	1,995,566	13.51–14.66
2. Urea-treated straw (UTS) feeding for local (indigenous) dairy cattle	10% of local dairy cattle can be targeted for UTS feeding starting in 2006, increasing annually at the GDP growth rate until 2030	60,258	1,431,387	43.66–45.99
3. Flood regulation through multiple aerations	10% of irrigated, intermittently flooded rice land under single aeration can be targeted for regulating flooding through multiple aerations in 2006, increasing annually at the GDP growth rate	933,120	23,133,946	3.01–25.03
4. Draining fields twice in rainfed, flood-prone, and deep water (50–100 cm water level) rice land	Draining fields twice in rainfed rice land was assumed to be a feasible abatement option, targeting 10% of land area under this water management regime in 2006 and increasing the targeted area annually at the GDP growth rate until 2030.	275,042	6,493,586	15.72
Forestry	*Subtotal*	*23,562,699*	–	
5. Conserving existing carbon pools/sinks	Deforestation rate to be reduced by 50% and plantation development to increase by 100% in Bangladesh, Nepal, and Sri Lanka. In Nepal, shrub land regeneration would increase by 50% with adequate protection. In Sri Lanka, the productive and protection plantation would increase by 5% per year. In Bhutan, the regeneration rate of modified natural forests to increase by 50% and plantation development to increase by 100% per year.	15,440,512	–	0.58–194.79
6. Expanding the amount of carbon stored (stocks)		8,122,187	–	14.71–642.96

continued on next page

Table 27 *continued*

Sector/Abatement Option	Assumptions Related to the Abatement Option Used in this Study	GHG Abatement Potential (ton CO_2e)		Incremental Abatement Cost in 2020 ($/ton CO_2e)[b]
		2020	Total 2005–2030[a]	
Waste Generation	*Subtotal*	*1,519,329*	–	
7. Recycling	MSW disposed assumed to decrease at 1.0% per year because of recycling. Degradable organic component also assumed to decrease at 1.5% per year because of composting.	620,263	–	1.18–5.48
8. Composting of municipal solid wastes (MSW)		899,066	–	0.42–1.98
Industrial Processes	*Subtotal*	*2,605,542*	–	
9. Post-combustion carbon capture and storage (CCS) in cement production	One new 1 million ton capacity cement plant will be built in 2015 under both business-as-usual and abatement scenarios. In the base case, the new cement plant is structured as any other integrated cement plants. Under the abatement scenario, the plant is assumed to be fitted with carbon capture and storage technology. GHG emissions can be reduced by 77% and 52% through post-combustion CCS and oxy-combustion CCS, respectively. Cost estimates for CO_2 capture are based on costs for Asia (Barker et al. 2009). Costs for CO_2 transportation and storage are based on estimated values for the Indian subcontinent in IEA (2008).	1,555,246	–	139.05–155.78
10. Oxy-combustion CCS in cement production		1,050,296	–	137.24–153.74

– = no analysis, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

[a] This refers to cumulative GHG abatement potential for the 2005–2030 period.

[b] The range of incremental abatement cost in 2020 shows the variation across the four countries included in the analysis.

Sources: RECCSA1 country reports (unpublished).

In both Bangladesh and Bhutan, UTS feeding has the highest IAC by a large margin. In Bangladesh, the largest GHG abatement potential in 2020 comes from draining rainfed flood-prone rice lands twice, with a reasonable IAC of $15.72 per ton CO_2e abated. For rice cultivation, the lowest IAC per ton CO_2e abated is achieved through multiple aerations, while UMMB supplementation has the lower IAC between the two abatement options for livestock production. Multiple aerations of rice fields appear to be the best option in reducing GHG emissions in Nepal and Sri Lanka, with an IAC considerably larger (in Sri Lanka) than in the other three countries.

Forestry

Across the forestry sectors of Bangladesh, Nepal, and Sri Lanka, the GHG abatement potential in 2020 of conserving existing forests could be twice (about 15.44 million t CO_2e) that from expanding carbon stocks (8.12 million t CO_2e). In all three countries, the IAC per ton CO_2e abated by conserving existing carbon sinks appears to be considerably smaller than that achieved by expanding carbon stocks. At the country level, the conservation of existing carbon sinks in Nepal and expanding carbon stocks in Bangladesh posted the highest GHG abatement potential in 2020 at almost 9 million t CO_2e and about 4.6 million t CO_2e, respectively. In terms of IAC, conserving existing carbon sinks in Bangladesh appears to be most reasonable at $0.58 per ton CO_2e, while the expansion of carbon stocks in Nepal, the most expensive at $38.62 per ton CO_2e.

The conservation of existing carbon sinks includes protecting forest reserves, adoption of appropriate silvicultural practices, and controlling deforestation. Globally, several sectors are advocating payments for avoiding deforestation in developing countries under the so-called “reducing emissions from deforestation and degradation”, perhaps in the post-2012 Kyoto Protocol. This is in recognition that deforestation mainly in the tropics account for 20% of all GHG emissions (Denman et al. 2007). However, “the design and implementation of REDD policies will be neither simple nor straightforward, given the complexity of the social, economic, environmental, and political dimensions of deforestation. Many of the underlying causes of deforestation are generated outside the forestry sector and alternative land uses tend to be more profitable than conserving forests” (Kanninen et al. 2007).

Meanwhile, the simplest way to expand carbon stocks is to plant trees, preferably the fast-growing species that will accumulate more biomass and carbon in a given period of time. Under the Clean Development Mechanism (CDM), only reforestation and afforestation projects are allowed.

Waste Disposal

For this study, two GHG abatement options under waste management were considered: recycling and composting of solid waste. Recycling here refers to any activity (except for composting) resulting in the reduction of landfilled solid waste. The study assumed that municipal solid waste disposed decreased at 1% per year because of recycling. This translates to an average annual recycling that range from 34,464 tons of waste per year in Nepal to 132,320 tons per year in Bangladesh during 2005–2030.

Between the composting and recycling options to manage GHG emissions from waste disposal, composting solid wastes consistently posted the higher abatement potential and lower IAC per ton CO_2e in Bangladesh, Bhutan, Nepal, and Sri Lanka. With composting solid wastes, GHG reduction in 2020 ranged from 16,156 tons in Bhutan to about 737,500 tons in Bangladesh. Marginal abatement cost appears to be lowest (again) in Bhutan at $0.42 per ton CO_2e and highest in Sri Lanka at $1.98 per ton CO_2e. Nevertheless, the adaptation of both waste management technologies has a combined total GHG abatement potential of about 1.52 million t CO_2e in 2020.

Industrial Processes

In the IPCC Fourth Assessment Report, carbon capture and storage (CCS) featured as a potential tool for reducing GHG emissions, particularly those from industrial processes (Bernstein et al. 2007). While the technology is currently not yet being fully implemented at the commercial level, CCS is projected to be in its demonstration phase by 2015 (McKinsey and Company 2009). Hendriks et al. (2004) stated six general ways to reduce CO_2 emissions and discussed two process-related abatement strategies/options, i.e., applying a lower clinker/cement ratio by increasing the ratio of additives to cement, and removal of CO_2 from flue gas.

This study considered the industrial process-related mitigation options only in the case of cement/clinker production: (i) post-combustion CCS, and (ii) oxy-combustion CCS, in Bangladesh, Bhutan, Nepal, and Sri Lanka. Table 27 shows that, across the four countries, post-combustion CCS has a significantly larger GHG abatement potential of about 1.56 million t CO_2e in 2020, but at a slightly higher IAC than the oxy-combustion CCS option; it ranged from $139.05 per ton CO_2e abated in Bhutan to $155.78 per ton CO_2e abated in both Bangladesh and Sri Lanka. Together, the two GHG emission mitigation options have an abatement potential reaching about 2.61 million t CO_2e in 2020.

Summary

Below are key results from the regional synthesis and country studies presented in this chapter.

In the **base case**, South Asia (excluding India) is projected to become more fossil fuel dependent during 2005–2030. Coal's share in the energy mix will increase significantly, especially in Bangladesh. Oil will remain a significant source of energy, although its share in the energy mix is expected to decline. For power (electricity) generation, the shares of petroleum products, hydropower, and natural gas are expected to decline, while that of coal, nuclear resources, biomass, and other renewable resources would increase. In nominal terms, the industrial, transport, and residential sectors are the major energy-consuming sectors in South Asia (excluding India), and the commercial and industrial sectors are the fastest growing. The total energy-related GHG emissions from the region (excluding India) would increase at a CAGR of 5.9% during 2005–2030, reaching about 244.7 million t by 2030. The power generation sector would remain the single largest energy-related GHG-emitting activity. The contributions to GHG emissions of the transport and residential sectors would decrease with the increasing adoption of cleaner and efficient vehicles and cooking stoves.

Under the **carbon tax**, the total primary energy supply of South Asia (excluding India) would be slightly lower than in the base case, with the energy mix moving toward natural gas, hydropower, biomass, and other renewable resources. The region's total power generation capacity in 2030 would be 3.26% higher, although the power generated would be 0.8% lower. Coal- and oil-based electricity generation would be substantially reduced, while that from natural gas (and nuclear power plants, particularly in Bangladesh and India) would increase. Carbon tax would reduce the 2030 total sector energy consumption in South Asia (excluding India), albeit only by 1.0% from the base case level. Energy consumption in the commercial and industrial sectors is estimated to increase in 2030, but these would be offset by the lower energy use from the residential and transport sectors. These reductions in energy consumption are due to the use of more efficient air cooling and refrigerators, fuel switching, and use of biodiesel, especially in vehicles.

With the carbon tax, there would be a cumulative reduction in GHG emissions in South Asia (excluding India) of around 971 million t of CO_2e during 2005–2030, with total annual emission decreasing by 22% in 2030. Power generation offers the largest potential for reducing GHG emissions, followed by the residential and commercial sectors. However, the imposition of a carbon tax would slightly increase the total discounted energy system cost from the base case level, as well as the nominal total investments for power generation.

For South Asia (excluding India), a GHG abatement cost analysis showed significant potential for GHG mitigation (or emissions reduction) at negative or low abatement costs. Total GHG emissions would decrease, and percentage reductions from the base case emission level would increase, with increasing per-unit CO_2e IAC. Base case GHG emissions could potentially be reduced by about 9.7% in 2020, by deploying several "no-regret" clean and energy-efficient options. The residential, transport, and industry sectors have the highest potential for mitigating energy-related GHG emissions.

The analysis of emissions from activities not using energy showed that for 2020 the use of urea-molasses multi-treatment blocks in livestock production, multiple aeration in rice cultivation, conservation of existing carbon stocks in the forestry sector, composting municipal solid wastes, and post-combustion carbon capture and storage in cement production have high GHG abatement potentials at low per-unit IAC.

Several of the energy-efficient GHG emission abatement options analyzed in this study are already found cost-effective under the base case. However, while they are cost-effective from an economics perspective, most of the abatement options are yet to be widely promoted and adopted. It is thus imperative to introduce policies and measures to overcome the various constraints and barriers that hinder the wide-scale use of such clean technologies and resource options. These policies and measures would greatly help the countries in South Asia move to low-carbon and green growth development.

5 Challenges and Enabling Conditions

Most South Asian countries are still developing and can pursue sustainable and low-carbon development strategies that support high economic growth and reduce GHG emissions at low or even negative costs (benefits). Already, the increasing application of cost-effective and energy-efficient technologies across the region is evident from declining energy-related GHG emissions per unit of GDP projected for the next two decades.

There remain however numerous technical, information, financial, and institutional barriers for clean technology development (Figure 31). Effective policies and measures would be necessary to overcome these barriers and constraints and to create an enabling environment for the larger-scale promotion and wider adoption of cleaner technologies and resources in South Asia.

Challenges to Clean Technology Development

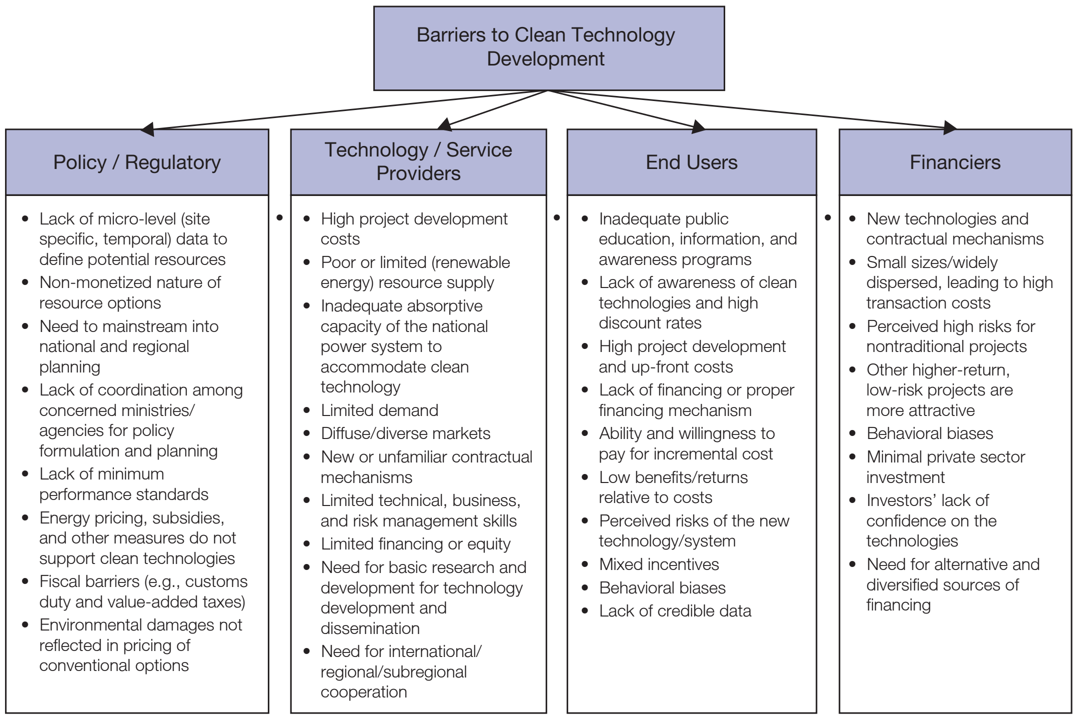
Technology-Related Constraints

Technology-related constraints include poor and limited resource supply or availability, in particularly the lack of combustion-efficient quality raw materials for dendrothermal power development. In Sri Lanka, for example, the development of renewable energy-based systems (e.g., wind and wood fuel-fired plants [dendrothermal power]) is hindered by lack of suitable materials.

A second technology constraint is inadequate absorptive capacity of the power system (national grid) to accommodate renewable energy sources, which is also true in Sri Lanka (Senanayake 2009). In India, the unavailability of transmission infrastructure and grid integration restricts the development of small hydropower and wind energy projects, especially in remote locations. While the states ought to provide the transmission infrastructure of renewable energy projects, the project developers, in reality, end up having to establish them and incur additional costs. The additional financial burden can discourage proponents from developing and pursuing cleaner technology projects. For example, a 20-MW project in Toos, Kullu (Himachal Pradesh, India) was scaled down to 10 MW due to the absence of adequate transmission infrastructure (IDFC 2010).

Renewable energy technologies, particularly those for electric power generation, are relatively new and sophisticated for most countries in South Asia. The countries are still

Figure 31 **Barriers to Clean Technology Development in South Asia**



Source: Adapted from WEC (World Energy Council). 2000. *Renewable Energy in South Asia—Status and Prospects*. November. London. http://www.worldenergy.org/documents/saarc.pdf and Sarkar, A. and J. Singh. 2010. Financing energy efficiency in developing countries—lessons learned and remaining challenges. *Energy Policy.* 38(2010): 5560–5571.

learning the technologies and developing their technical expertise and facilities required for the successful implementation of appropriate renewable energy projects. As such, there is a limited number of knowledgeable and capable personnel for the design and establishment, operation and maintenance, as well as promotion and dissemination of clean technology projects. This is further compounded by inadequate information and awareness programs for technology dissemination in the relevant economic sectors. In Bangladesh and India, unavailable data and information, lack of proper expertise, and limited government research and development support are cited as the main barriers to clean technology development (IDFC 2010; Rahman et al. 2012).

Financial and Economic Constraints

Many renewable energy technologies are at an early development stage and their risks are not yet clear or fully understood. The large-scale commercialization of some clean technologies is also hampered by the lack of minimum standards for performance, durability, reliability, and related parameters, as well as by high initial capital investment requirements (IDFC 2010). In India, for example, the expected performance of solar thermal technology—yet to be developed in the country—has not been ascertained. The high initial costs of establishing solar photovoltaics and thermal manufacturing plants restrict the wider adoption of solar energy-based clean technologies.

There also is a general lack of financing and absence of proper financing mechanisms for clean technology development in the region. In addition, the mainstream financial institutions in South Asia have limited understanding of and expertise on renewable energy and energy efficiency projects and are not yet prepared to finance them. Such factors are detrimental to potential financing for individual loans to purchase or install clean energy devices, or to making investments in clean energy programs and projects. The financing problem seems to be more severe for small-scale clean energy projects across the region, including in India (Box 1).

Box 1 **Financing Barriers to Renewable Energy Projects in India**

Renewable energy projects are reported to be facing financing difficulties in India. In general, their development is confronted with challenges in obtaining competitive forms of finance due to lack of familiarity and awareness of technologies, perception of high risk, and uncertainties regarding resource assessment. Specifically, the risk of nonprovision of subsidies due to limited or nonavailability of resources with the government is also significant because these subsidies may be the lifeline of the project.

Developers of renewable energy projects in India are often small, independent, and newly established entrepreneurs. They lack the institutional track record and financial inputs necessary to secure non-recourse project financing. Lenders perceive them as high risk and are reluctant to provide such project finance.

In addition, the paperwork and costs associated with identifying and obtaining access to financing for small- and medium-scale renewable energy projects is high relative to the financing needs. The financial institutions' limited understanding or expertise in this area likewise is a barrier to projects' access to financing.

Source: IDFC (Infrastructure Development Finance Company Ltd.). 2010. *Barriers to Development of Renewable Energy in India and Proposed Recommendations*. http://www.idfc.com/pdf/publications/Discussion-paper-on-Renewable-Energy.pdf

In Sri Lanka, for example, the lack of a consumer finance scheme is a major constraint to continued growth of solar home systems. The present loan schemes of local banks and other financial institutions in the country do not accommodate small-scale renewable energy projects, unless these are integrated with an income-generating activity (such as a rural industry), and/or providing fuel for domestic energy applications. These requirements came about from the banks' past experiences of poor loan recovery in rural areas (Senanayake 2009). Renewable resource-based electricity generation projects are also confronted by loan interest rates higher than those for conventional power plants; and high transaction costs due to high costs of resource assessment, project planning, design, and approval, and financing and power-purchase contract negotiations.

In Bhutan, mobilizing financing is a major challenge to developing a $12 billion–$15 billion 10,000-MW hydropower program, which is intended to generate power for export to India. Although bilateral loans from the Government of India finance most of the projects under the program, several joint ventures between the Druk Green Power Corporation and Indian public sector entities require commercial financing to supplement the official bilateral financing (ADB 2010a). In particular, Bhutan needs support in pursuing grid-connected renewable energy projects, including small hydro-power projects below 25 megawatts; developing follow-up public-private partnership transactions at the Dagachhu hydropower project; and increasing the focus on the environmental sustainability of large hydropower development.

In Nepal, private sector investment on renewable energy is minimal, mainly because of high risks perceived with, and investors' lack of confidence in, the technologies. To date, no commercial bank provides loans to promote renewable energy technology in the country, and available external/international donor funds are also limited (APCTT-UNESCAP undated).

In recent years, governments in South Asia have set up institutions for financing cleaner energy technologies. Examples include the Indian Renewable Energy Development Agency (IREDA), Nepal's Alternative Energy Promotion Centre (AEPC), and the Infrastructure Development Company Limited (IDCOL) in Bangladesh. These institutions play important roles in the clean energy market, but have limited funding capacity. As many clean energy projects tend to depend on often uncertain or delayed national budgets, alternative and diversified sources of potential funding should be identified and developed.

One option would have been private financing. However, critical financing gaps limit private investments in clean technology. In comparison to options in other sectors, investment in early-stage clean technology innovation is hindered by longer investment periods before exit, more capital-intensive development that requires large follow-on financing, smaller investment sizes coupled with similar due diligence costs and management fees, and higher execution risks than later-stage financing. Even after commercialization, lack of access to risk capital, project scale, and gaps in business skills remain significant barriers to investment for widespread deployment of clean technologies (Nassiry and Wheeler 2011).

Policy and Regulatory Barriers

Energy Pricing and Subsidies

Direct and indirect subsidies on fossil fuels and electricity are not conducive to the promotion of cleaner energy technologies in many South Asian countries. For example, in India, power tariffs are underpriced and subsidized, especially in the rural areas and some notified[33] industrial areas (India Solar 2012). Similarly in India's power sector, subsidies are effectively being provided to conventional fossil fuel resources, creating the false impression that renewable energy-based power is much more expensive than conventional power supply options (IDFC 2010). In Nepal, the government-regulated tariff on retail electricity is a disincentive to independent power producers. The national electric utility has incurred a huge financial deficit due to the unsustainable, low retail tariff and relatively high buy-back rates at which it purchases power from independent producers.

[33] In urban planning, a "notified area" is any land area earmarked by legal provision for future development. The term also describes a village or settlement with a population between 10,000 and 20,000. A community of over 20,000 is considered a town under Indian law. Each notified area elects a notified area committee for its administration, which functions like municipality (http://en.wikipedia.org/wiki/Notified_area).

Fiscal and Regulatory Barriers

Customs duty and value-added tax (VAT) are additional barriers to the development of clean technologies. For example, the Government of Nepal, having no policy to promote clean vehicles, charged the electric car REVA more than 240% custom duty the first time it came to the country in the year 2000. While the government subsequently modified the policy, electric vehicles still face 40% custom duty and 13% VAT (K2D 2010). In Bangladesh, the high import duty and VAT on all raw materials (except solar panels) increase the cost of local manufacturing of solar accessories, thereby also of solar home systems (Grameen Shakti 2011).

Regulatory barriers to clean technology development exist in various forms in South Asia. For one, several countries lack legal provisions requiring utilities to provide network access to renewable energy projects. Transmission or distribution access is necessary for direct third-party sales between renewable energy producers and the final consumers, especially when the renewable energy resources are located far from population centers. In the absence of regulation, utilities may not allow favorable transmission access to renewable energy producers, and/or may charge high prices for transmission access.

In Bangladesh, a second form of regulatory barrier is the lack of standardized power purchase agreements for power generation from renewable energy technologies (REEEP 2012). In addition, the government approval process for renewable energy projects tends to be lengthy and difficult with the various ministries, agencies, and institutions involved.

Most states in India have no defined zoning policy to guide and regulate the appropriate physical location of biomass projects. It has been reported that biomass plants have come up in proximity to each other, negatively affecting the availability of fuels, and eventually rendering the projects unviable (IDFC 2010).

Untapped Cross-Border Energy Cooperation

A major stumbling block to developing regional energy projects in South Asia is the lack of agreements between or among countries for large-scale project development and cross-border power trade and transmission. So far only Bhutan has a cross-border energy cooperation with India to develop a high-voltage (400 kilovolt [kV]/220 kV) transmission network for power transfer to India and supply of the load centers in Bhutan, parallel with implementing a 10,000-MW hydropower program (ADB 2010a).[34]

Developing the huge untapped clean energy resources in South Asia for intraregional trade will help meet the region's energy demand and provide multiple benefits to the countries. Such trade would allow the countries to fully exploit economies of scale in energy resource development and supply and would improve their trade balances. Nepal has a huge trade deficit with India and its total export revenue is not enough to pay for the import of petroleum products. For small developing countries like Bhutan and Nepal, regional power trade would help develop the indigenous clean energy resources in a sustainable manner and provide additional revenues to support national development.

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[34] Bangladesh and India have signed on 11 January 2010 a memorandum of understanding to develop a transmission line for cross-border power trade and for India to supply 500 MW of power to Bangladesh. India and Nepal have also agreed to build a cross-border transmission line for limited power trade (GPRB MPEMR 2012c).

Enabling Conditions and Policies for Promoting Low-Carbon Development

While no single policy instrument can ensure the transition to a low-carbon economy, key enabling conditions necessary to achieve such transition include (i) promoting research and development (R&D) on green and low-carbon technologies; (ii) investing in necessary capacity building, education, and training; (iii) establishing a sound regulatory framework to create incentives for investment in low-carbon technologies; and (iv) pursuing stronger regional cooperation in energy development and trade.

Promoting Research and Development

Basic Technology Development

Basic R&D for technology development and technology transfer efforts will be important in promoting the use of clean energy in South Asia. Researchers, engineers, entrepreneurs, and funding agencies have to work together to develop technologies that implement and integrate renewable energy resources in addressing the region's energy needs and climate change concerns. South Asia has been strengthening its R&D in clean energy technologies and effectively promoting the overall development of the energy sector, but needs to do more.

Because many (but not all) clean energy resources and technologies are quite immature, and/or relatively costly, investments for initiatives supporting basic R&D up to field demonstration facilities will be needed for users to invest with confidence. Areas for technology development include the design, manufacturing, installation, operation, and maintenance of these clean energy systems, complemented with more focus on their efficiency of conversion, use and distribution, and reliability. R&D efforts, currently being made in a theoretical environment, ought to be made more relevant to local needs. More site-specific technology packages should be developed and their demonstration areas established.

Nevertheless, some activities relating to clean energy technology development have already been started in these countries. In Bangladesh, research and demonstration activities have led to large-scale use of solar photovoltaic by various organizations and NGOs like Grameen Shakti. Also, around 10,000 biogas plants have been installed around the country by the Bangladesh Council of Scientific and Industrial Research, Institute of Fuel Research and Development, Local Government Engineering Department, and a few other organizations, and activities promoting biogas technologies are similarly being undertaken. In India, the Wind Resource Assessment Programme, one of the largest programs of its kind, has been carried out to reassess the country's wind potential, covering around 900 wind monitoring and mapping stations in 24 states and union territories. India is the fifth largest wind-power producer in the world after Germany, USA, Denmark, and UK, with a wind power capacity of 1,870 MW (Status of Renewable Energy and Energy Efficiency (REEE) in South Asia, as cited in Jaswal and Das Gupta 2006).

An analysis of research publications in renewable energy across Asia during 2000–2008 shows substantial impact of R&D in recent years. Investment in sustainable energy has already soared, with research breakthroughs contributing not only to solving the energy crisis, but also supporting the country's economy and climate change mitigation targets. During 2008–2012, India invested $21 billion for renewable energy development, mainly on wind, solar, biofuels, and hydropower (US government data, as cited in Thavasi and Ramakrishna 2009).

Energy Efficiency and Conservation

With rising international oil prices, it has become more critical for countries in South Asia to more actively pursue R&D in the areas of energy efficiency and energy conservation for sustainable energy management. Countries have begun to focus on improving the efficiency of the energy conversion, transmission, and distribution systems to help bridge the gap between demand and availability, reduce the cost of generation in the short run, and reduce the investment needs for electricity production in the long run (Srivastava and Misra 2007; Thavasi and Ramakrishna 2009). For example, the efficiency of existing power generation stations could be improved through adoption of better maintenance and operating practices, and that of new plants can be improved with efficient technologies.

Evidence around the world from the past 3–4 decades indicates that energy-efficiency programs generally entail positive and multiple benefits for government, energy consumers, and the environment.[35] Such programs can conserve natural resources; reduce the environmental pollution and carbon footprint of the energy sector; reduce dependence on fossil fuels, thus enhancing energy security; ease infrastructure bottlenecks and impacts of temporary power shortfalls; and improve industrial and commercial competitiveness through reduced operating costs.

A combination of renewable energy sources and energy efficiency could provide a safer and cost-effective way to mitigate GHG emissions and combat climate change, enhance energy security, and establish long-term sustainable energy development in South Asia. Within the menu of feasible technical options currently available to help reduce GHG emissions from the energy sector, energy-efficient technologies stand apart as the most cost-effective. Wind power has been viewed as the cheapest and lowest-risk option among the renewables that could make it a major source of electricity in the future, and is predicted to contribute up to 29% of global power generation by 2030. With the large hydropower energy in India, the total share of renewable energy sources in power generation has been expected to increase to 40% by 2030 (Thavasi and Ramakrishna 2009). In addition, the implementation of energy-efficiency policies could result in nearly 36% of avoided GHG emissions by 2050.[36] More than two thirds of these GHG reductions could come from demand-side (end-use) energy-efficiency interventions across different sectors in developing countries (Sarkar and Singh 2010).

In South Asia, considerable scope for energy conservation, through demand-side management and end-use energy-efficient measures, exists in all countries. In India, 23%

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[35] Without energy-efficiency measures adopted from 1973 onward, energy use in 11 of the major Organisation for Economic Co-operation and Development countries (36 of global primary energy use) would already have been 56% higher in 2004. This represents fuel cost savings of over $500 billion. As the world's energy use continues to grow, there is a huge energy-efficiency improvement potential across many sectors that remains to be tapped (Sarkar and Singh 2010).

[36] The International Energy Agency developed a set of 25 policy recommendations that, if implemented, could reduce global carbon dioxide emissions by 20% per year by 2020 (IEA 2009).

reduction of electricity consumption from the present level is possible in different sectors, without foregoing any end-use benefits of energy. This would entail savings of about 30% in the agricultural sector, 25% in the industrial sector, 20% in transportation, and 20% in the domestic sector (Powerline 2004, as cited in Srivastava and Misra 2007). The People's Republic of China (PRC) has already been successful in this regard.[37] In general however, increasing energy efficiency in South Asia will be successful only if sound legal frameworks and technical standards are in place, short-term and long-term financing are sufficient, and public awareness and program participation is strong (Srivastava and Misra 2007).

Carbon Sinks

Another potential R&D area related to clean energy technology is carbon sinks. The forest ecosystem plays a significant role in the carbon cycling process; forests are considered the most important carbon sinks and involved in mitigating climate change at low cost. Hence, the Kyoto Protocol allows counting certain carbon sinks as part of a nation's emissions reduction commitment, within some limits, and even trading of carbon sinks between nations (Thavasi and Ramakrishna 2009). India, together with Association of Southeast Asian Nations (ASEAN) countries and Australia, PRC, Japan, Republic of Korea, and New Zealand, committed during the Third East Asia Summit to increase the cumulative forest cover in East Asia by 15 million ha by 2020. The rate of afforestation in India is one of the highest among the tropical countries (Lal and Singh 2000, as cited in Thavasi and Ramakrishna 2009), currently estimated to be 2 million ha per annum. India has planned to increase its carbon stocks from forests to 9.75 billion t by 2030 from the 2009 level of 8.79 billion t.

Investing in Capacity Building

Related to promoting R&D in clean energy technology is the importance of investing in relevant capacity building, education, and training. This will enable governments to (i) have a better understanding of energy use and impacts as they relate to GHG emissions, and of the role that the regulatory framework can play in guiding energy consumption and production behavior; (ii) identify opportunities for GHG emission reductions, to prioritize policy as well as investment interventions, and to mobilize private sector resources; and (iii) monitor and assess progress toward national GHG emission reduction targets. A number of isolated projects on clean energy are proving to be successful, and can be systematically studied and analyzed for their strengths and success factors. Relevant capacity-building initiatives and training programs can then be developed for stakeholders (WEC 2000).

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[37] The People's Republic of China (PRC) has focused most of its energy conservation policies in the industrial sector. One of the unique features of the PRC's drive for energy efficiency was the scale of institutional capacity developed (Sinton, Levine, and Qingyi 1998). Over 200 energy conservation technology service centers were created and attached to various ministries and municipal governments. These service centers worked most closely with the end users. In May 1994, a national center, The Dalian Chinese Energy Conservation Education Centre, was established and is apparently the PRC's largest and most advanced efficiency training facility. In 1998, the National Energy Conservation Law came into force, codifying the country's approach for promoting energy efficiency under a more market-oriented economic system (Jaswal and Das Gupta 2006).

International and regional organizations should continue to enhance their catalytic role, particularly in terms of capacity building and promoting regional and subregional cooperation. International cooperation for capacity building through training programs, study tours, and exchange visits in clean energy technology development will be important—both in the form of technology transfer from developed to developing countries and between developing countries (WEC 2000). In South Asia, experiences gained from within the region in technology development and market mechanisms can be more valuable than those from beyond the region because the former have matured in similar conditions. In addition, the countries' access to information on emerging clean energy technologies needs to be improved, especially for end-users to better understand energy systems and apply that knowledge in making daily decisions.

Sound Regulatory Framework and Incentive Mechanisms and Schemes

It will be important for governments in South Asia to remove their subsidies for commercial energy products, such as fossil fuels, LPG, and electricity that compete with clean energy technologies and resources. Subsidies for commercial energy products (i) distort market price signals, consumption, production, and investment decisions; (ii) typically weigh heavily on government budgets; and (iii) encourage higher and even wasteful energy consumption, resulting in higher levels of GHG emissions and local air pollution, and faster resource depletion. Removing such subsidies will provide clean energy technologies a level playing field in the energy market and encourage investments aimed at reducing consumption.

Green and low-carbon technologies and practices are sources of positive externalities through the reduction of GHG emissions. Such approaches as price support measures, tax incentives, direct grants, and subsidized loans will stimulate innovation and adoption of green technologies. Fiscal proceeds from the removal of subsidies on conventional energy sources and/or from the application of a carbon-tax policy can be used to subsidize low-carbon technologies and facilitate the shift toward a low-carbon economy, in a fiscally neutral manner.

Setting national goals/targets and developing an enabling policy environment and regulatory framework are important first steps in promoting cleaner technologies/options and achieving low-carbon development. Most countries in South Asia have set such national targets (Table 28), and drawn national action plans to support them. For example, India's National Action Plan on Climate Change (2008) includes the National Solar Mission, National Mission on Enhanced Energy Efficiency, and National Mission on Sustainable Habitat, each of which states policies and programs to promote cleaner technology options in the country (GoI 2008). Similarly, the Bangladesh Climate Change Strategy and Action Plan 2009 and Renewable Energy Policy 2009 promote renewable energy and energy efficiency as part of the country's climate change adaptation and mitigation strategy (GPRB 2009).

Since the early 1990s, the power sector in India has been going through a process of reforms and restructuring, one of which was the Energy Conservation Act 2001. The act provides for the legal framework, institutional arrangements, and regulatory commissions

Table 28 **Targets for Cleaner Technologies and Options in South Asia**

Country	National Targets
Bangladesh	To develop at least 500 megawatts (MW) of power from renewable energy by 2015 (GPRB MPEMR 2012a)
Bhutan	To generate 20 MW by 2020 through a mix of renewable energy technologies–solar: 5 MW; wind: 5 MW; biomass: 5 MW; others: 5 MW (RGoB DoE 2011)
India	To generate 15% of its energy requirements through renewable sources by 2020 (ABPS 2009). The National Solar Mission, a major initiative of the Government of India and state governments in India, has set a target to deploy 20,000 MW of solar power by 2022 (GoI MNRE 2011). The country has also made a voluntary pledge to reduce carbon dioxide emissions intensity by 20%–25% of 2005 levels by 2020.
The Maldives	To become carbon neutral in the energy sector by 2020, ensure 50% of the electricity is supplied from renewable sources by 2015, and reach a saving of 7.5% on final energy consumption over 10 years until 2020 through efficiency improvements.
Nepal	To increase the share of renewable energy from less than 1% to 10% of the total energy supply, and to increase the access to electricity from alternative energy sources from 10% to 30% (GoN 2011).
Sri Lanka	To have 20% of electricity supply generation by 2020 from nonconventional renewable sources (generation under 10 MW) (DSRSL MFP 2010).

MW = megawatt.

at the central and state levels to embark on an energy-efficiency drive in the country. The regulator's mandate is to determine the tariff for bulk and retail supply. Subsidies in tariffs are to be eliminated gradually and tariffs are to move toward cost of supply. A total of 24 states in the country have either constituted or notified the constitution of regulatory commissions. The central government formally appointed a Bureau of Energy Efficiency to implement the act, with the primary objective of reducing energy intensity in the different sectors of the Indian economy (Jaswal and Das Gupta 2006).

Policies and measures for low-carbon development include market-based instruments (e.g., carbon prices), command-and-control mechanisms (e.g., by creating minimum standards or prohibiting certain activities), and industry self-regulation and voluntary agreements between government and businesses. Some can be purely domestic measures, while others have significant potential at the regional level.

Market-Based Instruments

Subsidies and favorable tax policies. Subsidies/tax incentives are likely to be needed to help reduce the initial costs of cleaner technologies and promote their move from initial phases of commercialization to accelerated growth and wider adoption. India provides power plants using biomass and agricultural waste with a subsidy of Rs0.80 million–Rs1.0 million (about $17,500–$21,900) per MW generated, and those based on bagasse with Rs3 million–Rs5 million (about $65,800–$109,700) per MW generated. Small hydropower plants are entitled to a subsidy of 10%–20% of the project cost (GoI MNRE 2011).

Subsidies or some other favorable tax policies are also applied to encourage the use of electric vehicles. For example, electric vehicles are tax free in Bhutan (RGoB DoE 2011), while India provided a subsidy of Rs75,000–Rs93,000 ($1,645–$2,040) per unit through a program conducted from 2010 to March 2012.[38] The subsidy was later withdrawn to make way for a new policy called National Mission for Electric Mobility 2020, which came into force by July 2012. The subsidy's withdrawal reportedly led to a 50% drop in the sales of REVA, the domestically produced electric vehicle in India (TET 2012a), clearly showing their sensitivity to prices and hence to taxes or subsidies.

In Bangladesh, the National Renewable Energy Policy exempts all equipment and related raw materials used in producing renewable energy from the 15% VAT. In addition, public and private sector investors in renewable energy projects are exempted from paying corporate income tax for 5 years. The government plans to extend the program periodically following an impact assessment (GPRB MoEF 2008).

Similarly, Bhutan exempts investors in renewable energy projects from paying corporate or business income taxes for a period of 10 years from the date of the project's commercial operation, applicable until 2025. The policy provides an additional 5-year tax holiday to projects established in the remote areas of the country, and exempts the project developers, manufacturers, and system integrators from all import duties and Bhutan sales tax on plants and equipment that are direct inputs to the renewable energy projects during the construction period. Investors in manufacturing and integration of renewable energy products in Bhutan are also exempted from paying income tax for a period of 10 years until 2019 (RGoB DoE 2011).

India also adopted a policy to allow accelerated depreciation (at 80% of equipment cost) and generation-based incentives (subsidy per unit of electricity generated fed into the power grid) for the development of wind power as mutually exclusive schemes (Box 2). These schemes are largely responsible for the country's rapid growth in wind power capacity from 7,000 MW in 2007[39] to 17,600 MW by 2012. Although, the policy was recently rolled back as part of the country's tax restructuring process, a policy allowing a 10-year tax holiday and excise duty exemption for the manufacture of wind power plants and their parts is now in place (GoI MNRE 2011).

To promote the use of energy-efficient lighting, the Government of India launched a program in 2009 distributing highly subsidized compact fluorescent lamps (CFLs) to households in exchange for incandescent lamps. The program has been successfully implemented in Kerala and Karnataka states. It is estimated that a significant amount of power generation capacity would be avoided through the replacement of the conventional lamps with the CFLs in India (Box 3).

However it should be noted that continuous provision of subsidies can bring about other problems. Various studies have shown that once a subsidy policy is announced, the prices of these technologies increase immediately by 10%–20%. The quality of the delivered technology is another question. For example, without quality control, consumers would pay more for a unit of biogas and solar energy due to the required continuous maintenance. A long-term policy on subsidy (what, how much, and until when) should

[38] Source: http://articles.timesofindia.indiatimes.com/2012-09-03/india/33562836_1_electric-mobility-electric-vehicles-ministers

[39] Source: http://www.inwea.org/installedcapacity.htm

Box 2 Generation-Based Incentives for Wind and Solar Power in India

Generation-based incentive (GBI) for renewable energy is a subsidy provided per unit of renewable energy-based electricity generation that is fed into the grid. Until recently this policy was implemented in India, where wind farms are eligible for a subsidy of Rs500 per megawatt-hour of electricity fed to the grid for a period of 4–10 years with a cap of Rs6.2 million per megawatt.

A similar scheme is also implemented in a limited scale in the case of solar energy in India. The GBI is provided to support a number of small solar power projects that are connected to the distribution grid (below 33 kilovolt) to the state utilities. At present, the total amount of subsidy in the form of GBI for the scheme is kept fixed as the difference of the solar power tariff determined by the Central Electricity Regulatory Commission for 2010–2011 and a reference tariff.

Source: GoI MNRE (Government of India, Ministry of New and Renewable Energy). 2011. *Strategic Plan for New and Renewable Energy Sector for the Period 2011–17*. New Delhi.

Box 3 Bachat Lamp Yojana in India

The Bureau of Energy Efficiency, a statutory body under the Union Power Ministry, launched a project in February 2009 to replace 400 million incandescent lamps with compact fluorescent lamps (CFLs) across the country. It is estimated that, once achieved, this will save the country 6,000 MW of power, or around Rs250 billion. Called the Bachat Lamp Yojana, the scheme envisages providing two CFLs of 14 or 16 watts, which cost around Rs70 each when bought in bulk, to every electrified household, at the highly subsidized price of Rs15 per lamp, in exchange for two incandescent lamps.

This scheme encourages private investment in efficient lighting, by leveraging carbon finance under the Clean Development Mechanism of the Kyoto Protocol.

In three years, more than 25 million CFLs have been distributed. Kerala was the first state to recognize the potential in reducing peak demand and provided 1,270 million CFLs to the household sector in 2010. The Energy Management Centre, Kerala, and Kerala State Electricity Board, distributed CFLs to all the households as replacement to incandescent bulbs. The scheme has benefited the consumers by reducing their electricity bills and has had a moderating effect on the demand-supply situation in Kerala.

According to statistics released by the Central Electricity Authority, the gap between demand and supply for Kerala declined from 2.4% in 2009–10 to 1.4% in 2010–11, while the gap at the national level remained at 12%.

Source: Business Today. 2012. *Flickering Hope*. http://businesstoday.intoday.in/story/fluorescent-lamps-demand-fluorescent-lamps/1/21982.html

be announced and followed in totality. Such policy should be oriented to lifting direct subsidies after a certain period. The mechanism of time value of money can be introduced to show decreasing subsidies over time (WEC 2000).

Feed-in tariffs/tariff incentives. With a feed-in tariff (FIT), the producers of electricity using renewable energy resources would be able to sell their surplus electricity to the power distribution grid at prices higher than that of electricity produced from non-renewable energy sources. Associated with FITs is the policy to provide renewable energy producers access to the electricity distribution system. As such, a properly designed FIT system would help renewable energy developers overcome the high costs of power generation and distribution, and limited access to the electricity market. Both India and Sri Lanka applies FITs to wind- and solar-based electricity. The FIT scheme implemented in Gujarat state, India has been widely reported for its remarkable achievement in solar power development (Box 4). In Bangladesh, electricity generated from renewable energy sources receives incentive tariffs, which may be up to 10% higher than the highest purchase price of electricity by the utility from private generators (GPRB MoEF 2008).

Box 4 **Solar Success in Gujarat, India**

The State of Gujarat in India saw the signing of 961.5 megawatt (MW) power purchase agreements by 87 national and international developers with the announcement of the Solar Power Generation Policy in 2009.

The incentives provided under the policy allow (GEDA 2012):

- Solar power generation for projects up to of 500 MW;
- Purchase price of electricity from solar photovoltaic at Rs15.00 per kilowatt-hour (kWh) for the first 12 years and Rs5.00 per kWh for the next 13 years;
- Purchase price of electricity from solar thermal at Rs11.00 per kWh for the first 12 years and Rs4.00 per kWh in the 13th year; and
- 10% renewable power purchase obligation.

The feed-in tariff of Rs15 per unit for the first 12 years and Rs5 per unit for the subsequent 13 years prompted the corporate sector to set up solar power generation plants in the state. The state has 605 MW installation capacity of solar PV compared to 200-odd MW by the rest of India. Gujarat has already met its target of 500 MW for 2014.

Source: IFC (International Finance Corporation). 2012. *India: Gujarat Solar.* Success Stories—Public–Private Partnerships. IFC Advisory Services in Public–Private Partnerships. Washington, D.C.

Renewable energy certificates. Renewable energy certificates (RECs) are certificates issued to producers of renewable energy-based electricity generated and injected into the distribution grid. A market-based instrument, it enables companies that intend to purchase clean power or are required to meet renewable purchase obligations, to do so by buying RECs from sellers in the market. India introduced the REC scheme in 2011 to kick-start its renewable energy market. It also introduced the solar-specific REC mechanism, which allows solar power generation companies to sell RECs to utilities, for the latter to meet their solar power purchase obligations (GoI MNRE 2011).[40] For now, solar RECs in India are traded between two power trading exchanges, the India Energy Exchanges (IEX) and the Power Exchange India Ltd. (PXIL). The REC mechanism is yet to be introduced in other countries in South Asia.

Energy-saving certificates. Energy-saving certificates are designed to promote the efficient use of energy. Under the scheme, enterprises using energy efficiently are

[40] In India, a unit of REC is equivalent to 1 megawatt-hour of electricity injected into the grid from renewable energy sources.

rewarded for energy savings against (below) the standard energy consumption level set for them. Certificates are issued to the enterprises for the amount of savings achieved. The certificates can be purchased by firms that find it difficult to operate within their stipulated energy consumption limits or standards. The scheme originated in Europe (called the EU White Certificate Program) and was introduced in April 2012 in India (GoI MNRE 2011).

Regulatory or Command-and-Control Mechanisms

Purchase obligation. Under the renewable energy purchase obligation (REPO) in India, the State Electricity Regulatory Commissions require power distribution licensees to purchase a minimum level of renewable energy out of their areas' total electricity sales. For example, India's National Solar Mission is targeting to deploy 20,000 MW of solar power by 2022. To achieve this goal, the State Electricity Regulatory Commissions are required to fix a percentage of energy purchase from solar power under the REPO (also called the solar power purchase obligation). The solar REPO may start during Phase I by 2013 with 0.25% of the total electricity sales, and increase to 3% by 2022.

Power access and evacuation infrastructure. Renewable energy projects often have poor or limited network access from utilities because their resources are generally located far from the demand centers, and some of them (solar and wind) operate intermittently. Utilities have been required to give producers of renewable energy access to their transmission/distribution network, for which the two parties enter into a simple and certain standard power purchase agreement. This is currently practiced in Sri Lanka (DSRSL MFP 2010).

Building adequate capacity to evacuate power is an important factor for promoting and developing renewable energy for large-scale power generation in South Asia. Infrastructure to transmit power generated from sites of renewable energy sources (like wind, solar, biomass, and small hydropower) to the demand centers will be required for South Asia to fully utilize the said power generation capacity. The development and provision of such infrastructure will prove to be economically feasible and environmentally sustainable in the long term. At present however, countries in the region lack sufficient capacity to transfer power generated from renewable energy sources.

Industry Self-Regulation and Voluntary Agreements

Energy efficiency/conservation code for buildings. In South Asia, significant energy is used in commercial (and residential) buildings due to the rapidly growing services sector. To address this concern, India launched an Energy Conservation Building Code in 2007, to achieve optimal energy use in buildings in different climatic areas, and to guide the design of new and large commercial buildings around the country (GoI MNRE 2011). It has been estimated that an energy saving of 30%–40% from the commercial building sector could be achieved if all commercial buildings follow the Code (GOI 2008). However, the code has been made mandatory in only eight of the 28 states of India to date. Most countries in South Asia lack a similar building code.

Developing sustainable transport. Rapid urbanization and the subsequent increasing number of private transport vehicles have led to higher energy consumption across the region. Only a few cities (India's Bangalore, Kolkata, Mumbai, and New Delhi) have a mass rapid transport system, and the development of railways, which are considered more energy efficient, has been lagging behind the growth in demand for long-distance transport services. Promotion of cleaner vehicles and modal shift to mass public transport (e.g., urban metro railway, bus rapid transport system, and inter-city railway) are some major options for energy-efficient low-carbon transport development in South Asia. Bhutan and Nepal, both with abundant hydropower resources, could opt for electric transport systems and enjoy several co-benefits of the technology (Box 5).

Box 5 **Potential Benefits of Transport Sector Electrification in Nepal**

Nepal is endowed with huge hydropower resources with a technical potential estimated at 83,000 megawatts (MW), of which 42,000 MW is reported to be economically viable. Nepal has almost has no indigenous fossil energy resources.

Only 1.5% of the economic hydropower potential has been harnessed and electricity use per capita is one of the lowest in the world. Oil imports are rapidly growing, mainly due to high growth in energy consumption in the transport sector. The country's total export revenue is no longer enough to pay for oil imports. The transport sector alone accounted for 5.2% of the country's total oil demand in 2008 and grew at the rate of 8.9% per annum during 2005–2009 (GoN WECS 2010).

A recent study (Shakya and Shrestha 2011) estimated that, without cleaner transport and climate policies, transport sector energy consumption by 2050 would be 12 times that in 2005. The sector would represent about 43% of total imported energy use and over two thirds of total petroleum product consumption by 2050. A shift of 20% of the road transport demand to electric mass transport system and shift of another 10% of the demand to electric vehicles in 2015, with the share of electric vehicles gradually increasing to 15% by 2050, would reduce by 14.7% the cumulative consumption of petroleum products during 2005–2050. This would also help promote hydropower development by creating demand for an additional hydropower capacity of 456 MW by 2050.

Co-benefits include a reduction in cumulative greenhouse gas emission by 17.6% during 2005–2050; decrease in cumulative emissions of local and regional pollutants—carbon dioxide, nitrogen oxides, sulfur dioxide, small particulate matter, and non-methane volatile organic compounds—by 9.9%, 10.9%, 7.2% , 6.7%, and 7.1%, respectively. Potential revenue from the sale of certified emission reductions generated by transport sector electrification, at $20 per ton of carbon dioxide equivalent, would cover about 4.9% of the total investment in the sector's electrification.

Clean Development Mechanism. Although not a financing mechanism per se, the Clean Development Mechanism (CDM) offers an opportunity to develop climate friendly projects in developing countries either through full funding from domestic sources (called a "unilateral CDM") or through partial or full funding from investors in industrialized countries (listed in Annex I of the Kyoto Protocol, "Annex I countries"). Certified emission credits (CECs) are issued to project developers for GHG emissions avoided through CDM projects in host developing countries. Low GHG intensive technology and resource options—e.g., energy-efficient technologies, renewable energy, cleaner transport options, technologies with carbon capture and storage (CCS), capture of methane from landfills etc.—are all eligible to be a CDM project, provided they meet certain criteria. The

CECs can be sold to parties in Annex I countries that could use them to meet their GHG reduction obligation.

By June 2012, about 8,971 projects around the world were in the CDM application pipeline, including 4,546 registered projects, 164 projects in the registration process, and 4,261 projects at the validation stage. Of the registered CDM projects, 1,717 (about 38%) have been issued CECs.

The six South Asia DMCs in this report hosts 2,342 projects, or about 26% of the global total, as of June 2012 (Table 29). India alone hosts 2,290 projects, which is 98% of the region's total and almost 30% of all projects in Asia that are in the CDM pipeline. India also has 18.4% share in the total volume of CECs issued in Asia. The numbers from the other South Asia DMCs are much lower. These indicate various barriers to the more active pursuit of CDM initiatives in the latter countries, ranging from lack of technical capacity to institutional or policy constraints. More specifically, the high transaction costs, long and time-consuming process in getting CDM projects approved or registered, lack of domestic finance to develop CDM projects, and recent decline in the prices of certificate of emission reduction (CER) in the international carbon market pose challenges to South Asian countries in their exploit of CDM opportunities (URC 2012).

Table 29 **Pipeline CDM projects in South Asia as of June 2012**

Type of Project	Bangladesh	Bhutan	India	The Maldives	Nepal	Sri Lanka	Total
Energy efficiency	5		388		4		397
Renewable energy			1,659			9	1,668
Hydropower		3	240		2	20	265
Landfill	2		40			1	43
Fuel switch			57				57
Transport			16				16
Reforestation			15				15
Others					4	2	6
Total	**7**	**3**	**2,290**	**0**	**10**	**32**	**8,971**

CDM = Clean Development Mechanism.

Source: URC (UNEP Risoe Center). 2012. *CDM Project Distribution within Host Countries by Region and Type*. Capacity Development for Clean Development Mechanism. Denmark. http://cdmpipeline.org/cdm-projects-region.htm

Despite existing challenges, South Asia—particularly India, Bhutan, and Nepal—continues to have significant potential for developing hydropower under CDM to help satisfy domestic power demand and for cross-border trade in the region. In fact, the 114-MW Dagachhu hydropower project in Bhutan, focused at supplying power to India, has been registered in 2010 as the first cross-border hydropower project under CDM in the world (see Box 6).

Regional Cooperation in Energy Development and Trade

Regional cooperation provides a major opportunity for South Asian countries to achieve energy security through large-scale development of clean energy resources. Successful cooperation in pursuing sound energy policies can be found across the world, particularly

Box 6 Bhutan's Dagachhu Hydropower Project—The First Cross-Border Clean Development Mechanism Project in the World

The 114-MW Dagachhu hydropower project in Bhutan, supported by the Asian Development Bank (ADB) and the governments of Austria and Japan, breaks new ground as the first cross-border project in the world under the Clean Development Mechanism (CDM), registered in 2010. Apart from enabling Bhutan to export clean energy to India, the project will also encourage cross-border power trade in South Asia by benefiting from international mechanisms like CDM.

The project is expected to reduce GHGs by about 500,000 tons per year mainly through power exports to India, whose electricity generation depends heavily on coal-fired power plants. The project will benefit India in reducing GHG emission, and benefit Bhutan by generating additional revenue from CDM to make the project viable in the country.

A notable feature of the Dagachhu hydropower project is the participation of multiple stakeholders (Bhutanese and international), making it the first public-private partnership for investment in infrastructure in Bhutan. The project is managed by Druk Green Power Corporation (DGPC), Bhutan's state-owned utility, and Tata Power Company, a leading energy company in India.

The total cost of the project is around $200 million, of which $80 million is loan committed by ADB. The National Pension and Provident Fund of Bhutan and Raiffeisen Zentralbank Österreich AG (RZB) of Austria provided co-financing to the project. The Austrian government provided engineering support through the Austrian Development Agency, while project structuring was promoted with assistance from the Japan Special Fund that is established by the government of Japan and administered by ADB.

Source: ADB. 2010b. *Bhutan Hydropower Project World's First Cross-Border Clean Development Mechanism Initiative*, ADB (http://www.adb.org/news/bhutan-hydropower-project-world-first-cross-border-clean-development-mechanism-initiative; downloaded from on 06.09.2012).

in sharing electricity generation through cross-border transmission interconnections. In Europe, electricity system interconnection has resulted in a 7%–10% reduction in generation capacity costs. Similar cooperation within the Greater Mekong Subregion in Southeast Asia has been estimated to potentially reduce energy costs by nearly 20%, for a saving of $200 billion during 2005–2025 (ADB 2012).

In South Asia, the existing intraregional energy trade is limited to electricity trade between India and Bhutan, and India and Nepal,[41] and trade in petroleum products between India and Bangladesh, Bhutan, Nepal, and Sri Lanka. While the electricity traded is based on indigenous hydropower resources, the petroleum trade is based on India importing and refining crude oil and exporting petroleum products to the other countries. India also exports diesel fuel to Bangladesh (ADB 2012).

Despite the abundance of clean resources in some of the countries, their development and utilization are currently low. For instance, only 28% (about 43,078 MW) of the region's

[41] India and Nepal have an active agreement to exchange power up to 50 MW. Due to lack of transmission capacity, however, it has not been possible to increase this power trade significantly. With the targeted completion of a new transmission line by 2015, Nepal has agreed to purchase 150 MW of power from India (World Bank 2011).

estimated 152,580-MW total economic hydropower potential have been installed (Young and Vilhauer 2003; GPRB 2011; GoN NEA 2011; RGoB NEC 2011; GoN WECS 2011; GoI MPCEA 2012; GoI MoEF 2012). Nepal, Bhutan, and India have so far installed and exploited only 1.5%, 5%, and 46% of their respective total economic hydropower potentials (Thapa 2011[42]; TET 2012b). The countries' ability to fully harness and better utilize these cleaner resources can be improved with the necessary technology, including modern control systems, commercial incentives, supporting infrastructure, and adequate financial resources (ADB 2012).

Regional cooperation in energy development and trade can also be viewed from another perspective. For one, the growing reliance of South Asia (particularly Bangladesh and India) on coal can be detrimental to both local and regional environment. This is because combustion of coal, biomass, and heavy fuel oil in the region are major sources of black carbon emission, a short-lived climate forcer. Black carbon emissions from activities like biomass or coal based indoor use in cooking have immediate health hazards. Such emissions could also accelerate melting of snow in the Himalayas, and in turn threaten the water security status of much of South Asia (USEPA 2012). Promoting the utilization and trade of cleaner energy resources in the region will therefore be important tools towards low-carbon and green development.

Given the above issues, areas in which regional cooperation could be strengthened to overcome the problems faced by clean energy technology development in South Asia include (i) sharing of manpower and technology know-how, (ii) technology training programs, (iii) sharing of environmental monitoring and information (especially those relating to renewable energy resources), (iv) sharing renewable energy resources (trade), and (v) a regional renewable fund (WEC 2000).

Sharing Human Resources and Technology Know-How

The liberalization and privatization process that has been introduced in some countries in South Asia has enhanced private sector involvement, thereby opening up new possibilities for access to technical know-how through market mechanisms. Mature technologies can be shared in the region and adapted for local conditions. The "terms and conditions" for such knowledge-sharing must be backed by governments and supported by market forces. Along this line, it may also be possible for India to encourage its companies to facilitate the transfer of clean energy technology to other countries in the region through joint ventures (if the other countries express interest in such ventures).

The human resources needed for policy making, planning, project implementation, management, and operation of energy systems could also be shared. Effective sharing, however, necessitates development of a new mechanism. For example, a regional energy center for South Asia could be set up supported by the governments in the region. In addition, a number of professional institutions and scientific and engineering organizations (e.g., academies of science, engineering institutions, and consultancy organizations) can be effectively utilized for regional experience sharing. Exchange

[42] http://www.ekantipur.com/2012/08/11/business/harnessing-of-hydropower-potential-nepal-nowhere-at-the-top-of-south-asian-countries-list/358586.html

of information on renewable energy R&D can also be arranged through seminars, workshops, study visits, etc.

Training Programs in Renewable Energy

Some progress has been made in cooperation in training in South Asia. India, for example, has been supporting technology-specific training courses, in which scientists and technologists from Bangladesh, Nepal, and Sri Lanka have participated. Two such training courses in small hydropower were organized during 1998–1999 and 1999–2000 through the Alternate Hydro Energy Centre at the University of Roorkee. A training program in biogas technology was held at the College of Technology and Agricultural Engineering, Udaipur. Six 2-week training programs in the areas of small hydropower, biogas, biomass gasification, solar thermal, solar photovoltaics, and improved cooking stoves were subsequently proposed by the Government of India.

Cooperation could also include exchange of officials/technologists to participate in training programs on different aspects of renewable energy, which could be organized at institutes of recognized technological excellence.

Sharing Environmental Information and Investment

Examples of sharing information and investments include

- **Sharing information from environmental monitoring institutions.** Setting up an institution for environmental monitoring and control is a time-consuming and costly proposition. Some of the existing institutions in the region can develop packages that will help in monitoring and controlling the quality of air and water, which are directly affected by energy use. Such an approach will fulfill obligations under the Kyoto Protocol and ensure sustainability of energy supply and systems in an environment friendly fashion.
- **Setting up environmental monitoring stations.** A constant vigil on environmental conditions will be necessary to promote the use of appropriate energy systems. This will call for low-cost environment monitoring equipment and processes at many points in a country. A regional network of environmental monitoring stations would be of great help.
- **Sharing investments in plants and machinery.** Such sharing could be mutually beneficial for the countries concerned and would build investor confidence. In view of low off-take in some countries, the bankability of investment proposals for a single country operation could remain difficult to justify.

ADB (2012) provides a succinct description of five benefits of regional cooperation and trade in (clean) energy in South Asia. Cooperation allows countries to balance their energy demand and supply, exploiting their unique comparative advantage while meeting increasingly diverse energy requirements and combating energy shortages. It supports the countries' economic growth—exporting resources in which they have a comparative advantage, and importing a wide range of other goods and services. When based on cross-border project financing, this allows for a win–win rationalization of resource costs and project benefits. Cross-border collaborative infrastructure development can ease the huge burden of energy infrastructure investment required. The opportunity to share project costs and benefits can reduce immediate financing burdens, smooth cash flows, and lower project risks for individual countries. Cooperation in energy policy can ease supply constraints, lower energy supply costs, and provide some protection against world oil price shocks. Lastly, regional projects offer the countries unique opportunities for climate change mitigation and receiving Clean Development Mechanism (CDM) benefits.

6 Conclusion and Way Forward

With energy demand in South Asia projected to more than double by 2030, this study reveals excellent opportunities in low-carbon green growth by pursuing a wide and varied range of resource- and energy-efficient technologies that would lower GHG emissions at low cost or even cost saving (benefits). Additional introduction of a climate policy—through, for example, a carbon tax—would further lower emissions.

Based on the constraints and opportunities discussed in this review, the areas of support to develop the diverse yet large potentials of South Asian countries for clean energy resources and technologies fall under three general headings—technology, policy, and finance—each of which may play a role in, and be influenced by, regional or subregional cooperation. In addition, political will on the basis of agreed strategies is vital for closer collaboration between governments and all other concerned stakeholders.

Technology

Significant carbon intensity and GHG emissions reduction can be achieved by South Asian countries by prioritizing investments in technologies across sectors with low IACs and other co-benefits, such as reducing emissions of other locally-damaging pollutants and providing economic opportunities for communities. The scope of these investments can cover (i) promotion of energy efficiency and development of renewable energy; (ii) low carbon transport infrastructure; (iii) urban services, including employing cost-effective and income-generating waste management mechanisms; (iv) energy-efficient buildings and other infrastructure; and (v) energy-efficient irrigation pumps, including use of solar energy. Some specific examples are energy-efficient lamps, air conditioners, and solar and electrical cooking stoves in residential and commercial sectors; energy-efficient electric motors and diesel boilers in industrial sector; efficient diesel tractors in agriculture sector; partial modal shifts in the road freight to railways in the transport sector; and shift to renewable sources for power generation. North-south and south-south cooperation should be encouraged in developing, demonstrating, and scaling-up potential clean energy technologies.

Policy

As in any other development initiative, an appropriate policy environment is prerequisite for a paradigm shift toward a sustainable energy future. The countries in South Asia have different experiences in policies, regulations, and development and deployment of various clean energy resources and technologies, and each can benefit from an institutionalized multi-pronged clean energy program. These country-specific programs can include initiatives increasing energy efficiency in relevant sectors; promoting the adoption of renewable energy resources; and improving energy access, especially of poor and remote regions. The clean energy programs and their elemental resources and technologies must be integrated into national development efforts and reflected in long-term energy policies and development planning processes. These in turn should be supported by various policy options that may include, among others, strategic development planning and management of energy and energy-related sectors; appropriate market and structural reforms, including clean energy pricing and subsidy policies; mechanisms for transboundary or regional energy cooperation and trade; and favorable financial support and innovative financing mechanisms for clean energy technologies.

Finance

The urgent need to address GHG emissions and climate change concerns in South Asia requires significant new investment in the development and deployment of clean energy technologies. Sources of financing for clean energy technology options may include mainstream financing institutions (i.e., commercial banks), government institutions established for the promotion of such technologies, NGOs/private organizations, and international financial mechanisms. In most South Asian countries however, mainstream financing institutions are not prepared to support renewable energy projects or provide loans to purchase cleaner technology devices. Some innovative mechanisms and policies are needed to reduce risks perceived by mainstream lending institutions in cleaner technology investments and to enhance their capacity for financing low-carbon technologies and resource options.

A recent development in this area is the Climate Investment Readiness Index from the International Bank for Reconstruction and Development/The World Bank (2012). The index scores the presence of important enabling policies, regulations, incentives, and institutions related to renewable energy and energy efficiency in South Asia, thereby contributing to better evaluation and understanding of the issues by governments and donor agencies, and to better targeting of external assistance based on identified key investment-related barriers. The index also fosters transparency, identification of weak spots in a country's climate investment situation, and consequent reform to enable greater investment in clean energy technologies.

Some examples of public agencies in South Asia that can provide financing for renewable energy projects are the Indian Renewable Energy Development Agency Ltd., Nepal's Alternative Energy Promotion Center, and Bangladesh's Infrastructure Development Company Limited. They however have limited resources and depend either on donor agencies or government for funds. In some cases, NGOs play an active role in promoting clean energy technologies using innovative financing and other schemes (Box 7). Bilateral funding sources, private financing, and many other international climate funds and funding mechanisms are likewise available for larger-scale clean energy development in developing countries, including South Asia.

Box 7 **Success of the Grameen Shakti Solar Home System in Bangladesh**

Grameen Shakti, a renewable energy service company, is installing 1,000 solar home systems a day in the rural areas of Bangladesh, where 80% of the country's population lives. By the end of 2012, it will have installed a total of 1 million solar home systems and has expansion plans to install 5 million systems by 2015.

Grameen Shakti meets the challenge of serving the rural market and reaching poor villagers by creating rural supply chains and after-sales service. The engineers and technicians live, work, and are trained on the job in the villages. They remain in close contact with the customers and ensure that the solar home systems are operating. If there is a problem, Grameen Shakti staff are on-site to assist.

The success of Grameen Shakti is mainly attributed to its innovative and affordable financing models as follows:

(i) The user pays 15% of the total cost as down payment. The remaining 85% is to be repaid within 36 months with 6% (flat rate) service charges.

(ii) The customer pays 25% of the total price as down payment. The remaining 75% is to be repaid within 24 months with 4% (flat rate) service charge.

(iii) Micro-utility: The customer pays 10% of the total price as down payment. The remaining 90% is to be repaid by 42 checks. There is no service charge.

(iv) A 4% discount is allowed on printed price in case of cash purchase.

Sources:
Grameen Shakti. 2011. *Renewable Energy: The Key to Achieving Sustainable Development of Rural Bangladesh*.
Wimmer, N. 2012. *Clean Energy Access For All—Grameen's Solar Success*. http://sierraclub.typepad.com/compass/2012/07/grameen-solar-success.html

One financing source that can be examined and applied in South Asia is the use of carbon tax revenues to fund research and development on clean technologies and resources, including the promotion and dissemination of matured ones. Such "recycling" of financial resources will make the shift to a low-carbon energy system and green economy cost-neutral.

Technology, policy, and financing issues will continue to influence the development of clean energy technologies and formulation of energy policies in the 21st century. While the responsibility lies with the national governments and other stakeholders to formulate and implement strategies toward a sustainable energy future, regional and subregional cooperation may help address some of the issues collectively and in a cost-effective manner. Examples of regional cooperation in energy in South Asia are the South Asia Regional Initiative for Energy (SARI-Energy) program, which helps improve access to economic and social infrastructure in the energy sector, and the South Asia Regional Energy Coalition, which is a networking mechanism through which sector stakeholders can influence regional energy policy and reform (Jaswal and Das Gupta 2006). Transfer of best implementation practices, policies, and technologies from developed countries, and also south–south interactions within and among developing countries will be the cornerstones of cooperation.

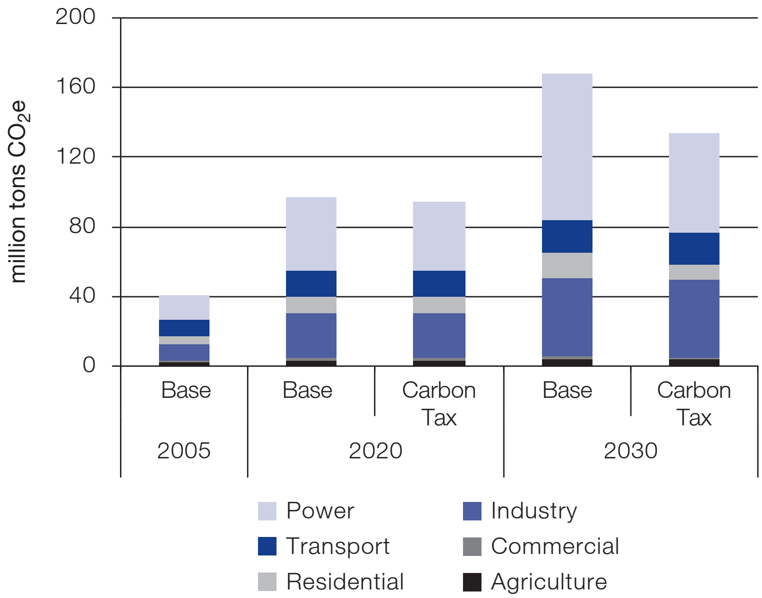
Large-scale development of clean energy resources is crucial for South Asian countries to reduce energy-related GHG emissions per unit of GDP over the next two decades. While a number of initiatives could be launched to help South Asia meet concrete clean energy targets in 2030 and beyond, it should be emphasized that their success will rely on effective cooperation among the various actors in energy and related sectors, both within and across the countries. South Asian countries need to have stronger commitment to achieving sustainable energy security, and firm understanding of its factors and requirements, for them to reap the benefits from international and regional cooperation for clean energy resource and technology development. Regional energy cooperation and trade as well as south-south and north-south cooperation on technology and knowledge sharing will pave the way for a move towards low-carbon and green development in South Asia.

Appendix 1
Country Summaries—GHG Emission Abatement Options and Costs in Energy-Using Activities and Key Sectors

Bangladesh

- Under the base case, total greenhouse gas (GHG) emissions are estimated to increase at 5.8% cumulative annual growth rate (CAGR) to reach 168.3 million tons of carbon dioxide equivalent (t CO_2e) by 2030, with the power sector contributing about 50% (Figure A1.1).
- With carbon tax, cumulative GHG emissions during 2005–2030 would be reduced by 9.4% from the base case level, with reductions higher in later years (e.g., 20.3% reduction in 2030). The cumulative GHG emissions from the power sector would decrease by 18.4% during 2005–2030, with additional nuclear, wind, and municipal solid waste-based power generation plants. Cumulative GHG emissions from the residential and commercial sectors would also decline. There would be no significant reductions from the transport and industry sectors.
- Approximately 10.5 million t CO_2e of GHG emissions, or about 10.7% of the base case, could be avoided in 2020 at no additional cost (negative incremental abatement cost) by deploying nine “no-regret” cleaner and energy efficient options in Bangladesh (Table A1.1).
- Among 23 cleaner technology options, replacing all conventional lamps in the residential sector with efficient compact fluorescent lamps (CFLs) has the highest annual GHG abatement potential of about 4.7 million t CO_2e in 2020, and at no additional cost (Table A1.2 and Figure A1.2).

Figure A1.1 **Sectoral GHG Emissions under the Base Case and Carbon-Tax Scenario, Bangladesh**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Table A1.1 **Total GHG Emission at Selected Incremental Abatement Costs, Bangladesh, 2020**

		Incremental Abatement Costs ($ per ton CO_2e)								
	Base Case	**≤ 0** (“No-regret” options)	**10**	**30**	**50**	**75**	**100**	**200**	**350**	**500**
Total GHG Emissions ('000 tons CO_2e)	97,237	86,786	75,702	73,287	72,409	72,409	72,399	72,399	71,755	71,704
GHG Reduction (%)		10.7	22.1	24.6	25.5	25.5	25.5	25.5	26.2	26.3
Sectoral Shares in Total GHG Emission Abatement (%)										
Residential		45.1	21.9	23.4	22.6	22.6	22.6	22.6	24.5	24.5
Commercial		0.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8
Transport		27.4	13.3	11.9	14.2	14.2	14.2	14.2	13.9	13.8
Industry		25.8	30.1	27.0	26.9	26.9	26.9	26.9	26.3	26.4
Agriculture		1.7	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Power		0.0	32.1	35.0	33.8	33.8	33.7	33.7	32.9	32.8

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Table A1.2 **Estimated Incremental Abatement Cost (IAC) and GHG Abatement Potential of Different Cleaner Technology Options in Bangladesh, 2020**

Rank	Cleaner Technology Options	Annual GHG Abatement Potential ('000 tons CO_2e)	Cumulative Annual GHG Abatement Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost (2005 $ per ton CO_2e)
1	Efficient CNG (90%) and gasohol (10%) cars replacing 100% of gasoline cars	44	44	(153.1)
2	Efficient diesel rail (20%) and efficient diesel trucks (80%) replacing 100% of road freight demand in the transport sector	1,863	1,907	(150.1)
3	Efficient diesel water freight vessels replacing 100% of the conventional diesel freight vessels in the transport sector	238	2,145	(21.8)
4	Efficient CFLs replacing 100% of the conventional lamps in the residential sector	4,718	6,863	(19.9)
5	Efficient diesel water passenger vessels replacing 100% of the conventional diesel passenger vessels in the transport sector	716	7,579	(19.8)
6	Efficient diesel pumps replacing 100% of conventional diesel pumps in agricultural sector	175	7,754	(16.0)
7	Efficient paddy parboiling & milling replacing 100% of the conventional paddy parboiling & milling technology in industry sector	329	8,083	(12.2)
8	Efficient boilers replacing 100% of conventional boilers in the paper, paddy parboiling & milling and textile industry	282	8,365	(6.4)
9	Efficient Hybrid Hoffman kiln replacing 100% of the conventional kilns in the brick industry	2,086	10,451	(2.6)
10	CFLs replacing 100% of conventional lamps in the commercial sector	401	10,852	1.0
11	Efficient technology replacing 100% of conventional technology in the fertilizer industry	3,716	14,568	3.6
12	Efficient continuous technology replacing 100% of batch process in the sugar industry	60	14,628	6.7
13	Nuclear power generation replacing 5% of total power generation	2,494	17,122	7.1

continued on next page

Table A1.2 *continued*

Rank	Cleaner Technology Options	Annual GHG Abatement Potential ('000 tons CO_2e)	Cumulative Annual GHG Abatement Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost (2005 $ per ton CO_2e)
14	Renewable power replacing 10% of total power generation[b]	4,413	21,535	7.9
15	Efficient fans and ACs replacing 100% of the inefficient fans and ACs in the residential sector	628	22,163	11.1
16	Gas fired power plants with carbon capture & storage replacing 5% of total power generation	1,475	23,638	20.1
17	Efficient refrigerator replacing 100% of the conventional refrigerator in the residential sector	258	23,896	20.9
18	Efficient fans replacing 100% of inefficient fans in the commercial sector	54	23,950	26.1
19	Efficient furnace replacing 50% of conventional furnace in iron and steel industry	210	24,159	33.4
20	Efficient fuel cell bus (5%) and CNG buses (95%) replacing conventional diesel bus in the transport sector	668	24,828	41.3
21	Efficient technology replacing 50% of conventional technology in the textile industry	11	24,838	92.6
22	LCD TV replacing 50% of the conventional TV in the residential sector	644	25,482	324.3
23	Efficient process technology replacing 100% of wet process in the cement industry	51	25,533	500.0

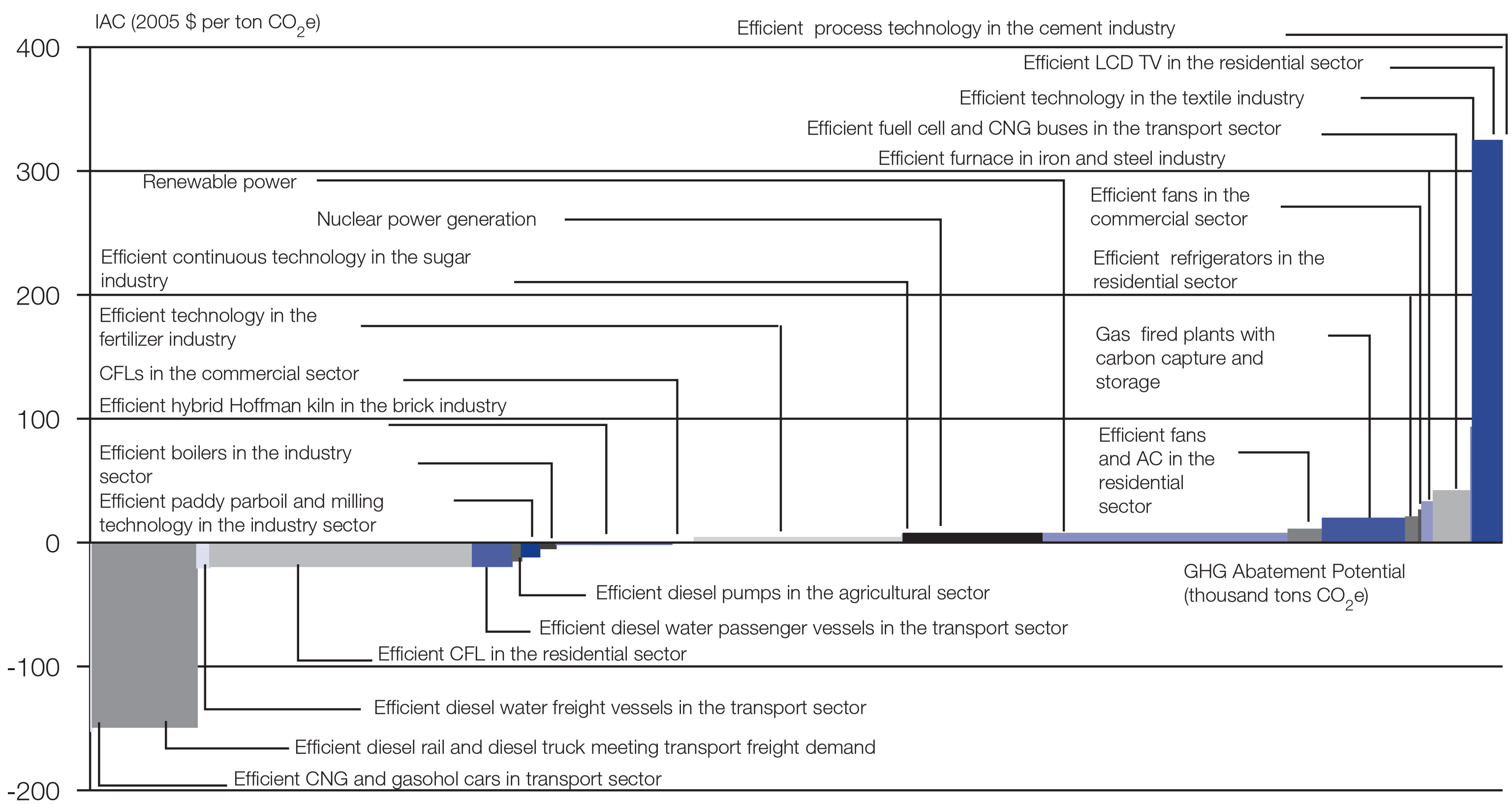
AC = air conditioner, CFL = compact fluorescent lamp, CNG = compressed natural gas, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LCD = liquid crystal display, PJ = petajoule, TJ = terajoule, TV = television.

[a] The cumulative potential here refers to the total amount of GHG emission abatement that could be attained if all options with the rank of the particular option or higher are deployed. For example, the cumulative potential figure corresponding to technology options up to rank number 2 means the sum of the GHG abatement potentials of technology options ranked 1 and 2.

[b] It includes power generation from a combination of different renewable energy resources and consists of 11.3 PJ from biomass, 6.6 PJ from municipal solid waste, 1.4 PJ from solar photovoltaic, and 3.6 TJ from wind.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Figure A1.2 **GHG Abatement Cost Curve for Bangladesh, 2020**



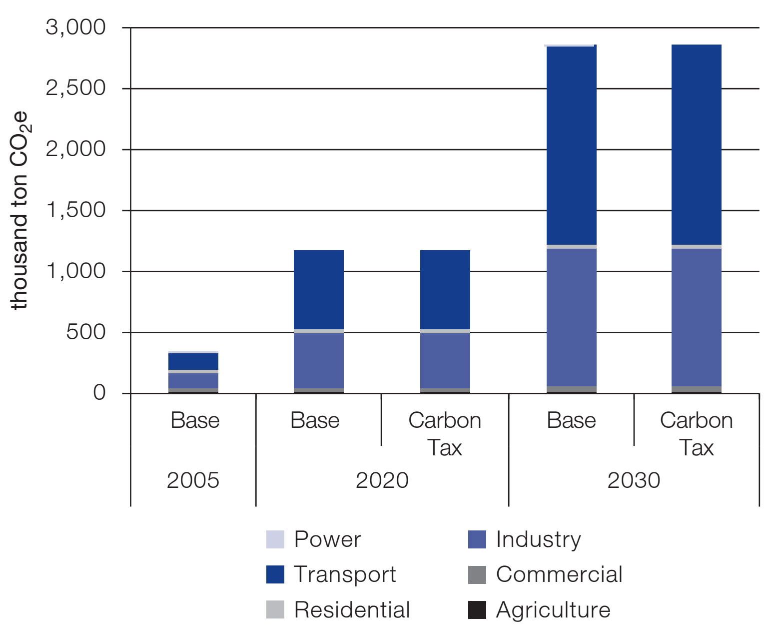
AC = air conditioner, CFL = compact fluorescent lamp, CNG = compressed natural gas, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, IAC = incremental abatement cost, LCD = liquid crystal display, TV = television.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Bhutan

- Under the base case, total GHG emissions would increase almost sevenfold at 9% CAGR to reach 2.9 million t CO_2e by 2030, with the transport sector contributing 57.5% and industry contributing 39.4% (Figure A1.3).
- With carbon tax, cumulative GHG emissions during 2005–2030 would decline by a very minimal 0.07% (about 20,000 t) from the base case level. The power sector would contribute about 91% in the total GHG emission reduction, followed by the transport sector. This reduction from power generation is mainly due to increased hydroelectricity production in 2030.
- A number of cleaner technologies and energy efficient options are found already cost effective in the base case, and will be important GHG mitigation strategies even without a carbon tax policy.
- Approximately 64,000 t CO_2e emissions (about 5.54% of total GHG emission) could be avoided in 2020 at no additional cost by deploying seven "no-regret" cleaner options in Bhutan (Table A1.4). Among 14 cleaner technology options evaluated in this study, replacing 80% of residential kerosene stoves with efficient electric stoves offers the highest GHG abatement potential of 18,600 t CO_2e emissions in 2020, and at no additional cost (Table A1.4 and Figure A1.4).

Figure A1.3 **Sectoral GHG Emissions under the Base Case and Carbon-Tax Scenario, Bhutan**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

Table A1.3 **Total GHG Emission at Selected Incremental Abatement Costs, Bhutan, 2020**

		Incremental Abatement Costs ($ per ton CO_2e)						
	Base Case	**≤ 0** ("No-regret" options)	**10**	**30**	**50**	**75**	**100**	**~400**
Total GHG Emissions ('000 tons CO_2e)	1,155.3	1,091.20	1,076.00	1,072.20	1,072.20	1,062.80	1,049.30	1,048.80
GHG Reduction (%)		5.54	6.87	7.19	7.19	8.00	9.17	9.21
Sectoral Shares in Total GHG Emission Abatement (%)								
Residential		39.60	32.00	30.60	30.60	27.50	24.00	23.80
Commercial		39.00	31.50	30.00	30.00	27.00	23.50	23.40
Transport		21.40	36.50	39.40	39.40	45.60	43.00	43.20
Industry		0.00	0.00	0.00	0.00	0.00	9.50	9.50
Agriculture*		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Power*		0.00	0.00	0.00	0.00	0.00	0.00	0.00

CO_2e = carbon dioxide equivalent; GHG = greenhouse gas.

* No mitigation options were considered in the agriculture and power sectors (the latter being predominantly hydro-based); this is the reason why there is no GHG abatement shown in the table from these sectors.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

Table A1.4 **Estimated Incremental Abatement Cost (IAC) and GHG Abatement Potential of Different Cleaner Technology Options in Bhutan, 2020**

Rank	Cleaner Technology Options	Annual GHG Abatement Potential ('000 tons CO_2e)	Cumulative Annual GHG Abatement Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
1	Replacing 50% of LPG stoves by electric stoves in residential cooking	15.1	15.1	(72.8)
2	Replacing 50% of LPG stoves by electric stoves in commercial cooking	6.4	21.5	(62.7)
3	Increasing the share of electric buses from 10% to 20% in Hill	10.8	32.3	(46.4)
4	Increasing the share of electric buses from 10% to 20% in Plain	2.6	34.9	(37.8)
5	Replacing 80% of kerosene stoves by electric stoves in residential cooking	10.3	45.2	(29.2)
6	Replacing 80% of kerosene stoves by electric stoves in residential cooking	18.6	63.7	(21.5)
7	Replacing 15% of diesel light vehicle by electric light vehicle[b] in Plain	0.3	64.0	0.0
8	Replacing 30% of gasoline taxis by electric taxis in Hill	15.3	79.3	6.5
9	Replacing 30% of gasoline taxis by electric taxis in Plain	3.7	83.0	11.2
10	Replacing 15% of gasoline light vehicles by electric light vehicles in Hill	9.4	92.5	63.6
11	Replacing 15% of diesel light vehicles by electric light vehicles in Hill	1.2	93.6	86.8
12	Replacing 50% of inefficient arc furnaces by efficient arc furnaces in iron and steel industry	10.1	103.7	89.0
13	Replacing 15% of gasoline light vehicles by electric light vehicles in Plain	2.2	106.0	89.0
14	Replacing 30% of gasoline 2-wheelers by electric 2-wheelers in the transport sector	0.5	106.4	416.7

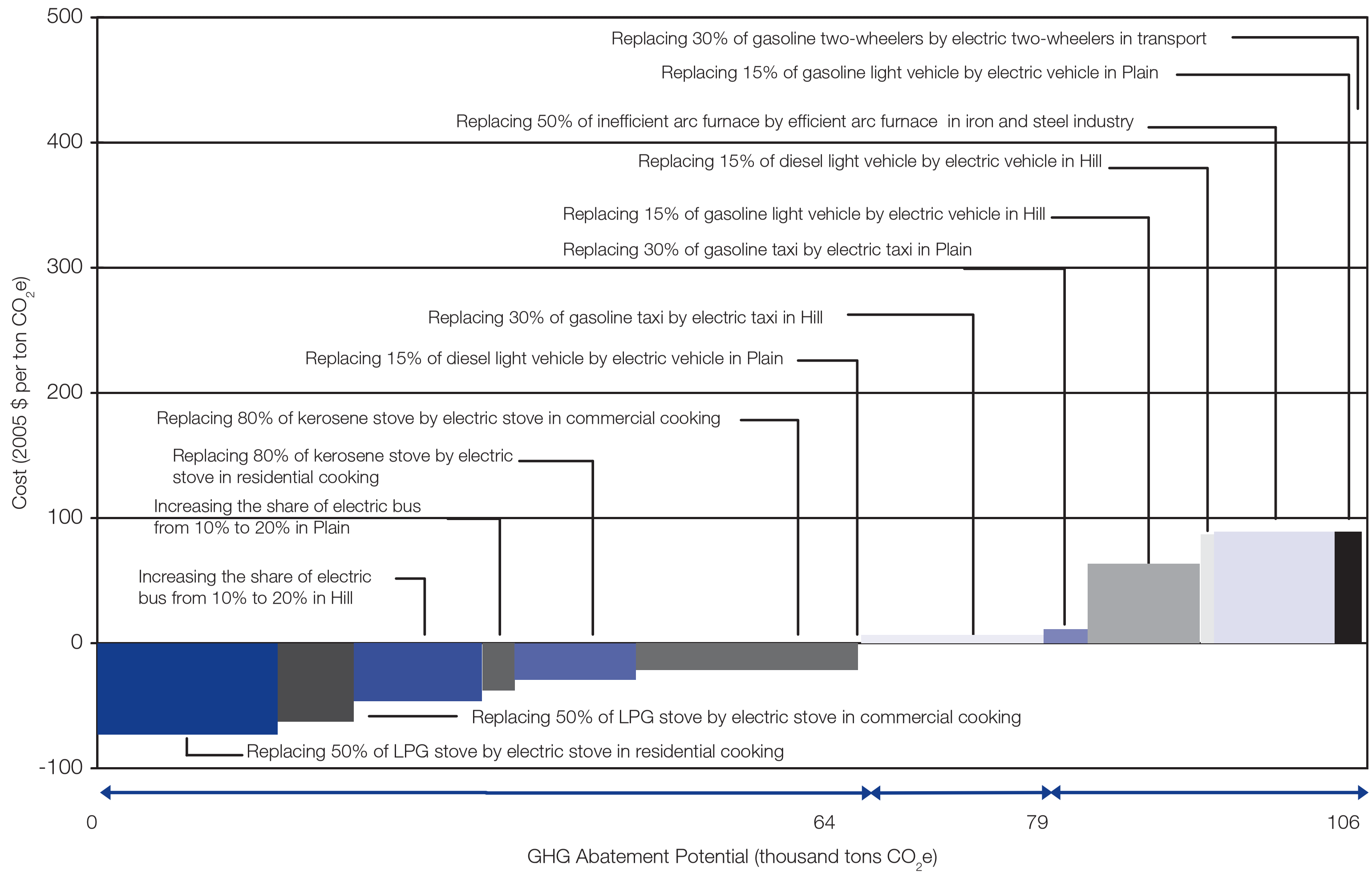
( ) = negative, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LPG = liquefied petroleum gas.

[a] The cumulative potential here refers to the total amount of GHG emission abatement that could be attained if all options with the rank of the particular option or higher are deployed. For example, the cumulative potential figure corresponding to technology options up to rank number 2 means the sum of the GHG abatement potentials of technology options ranked 1 and 2.

[b] Light vehicles include cars, jeeps, and vans.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

Figure A1.4 **GHG Abatement Cost Curve for Bhutan, 2020**



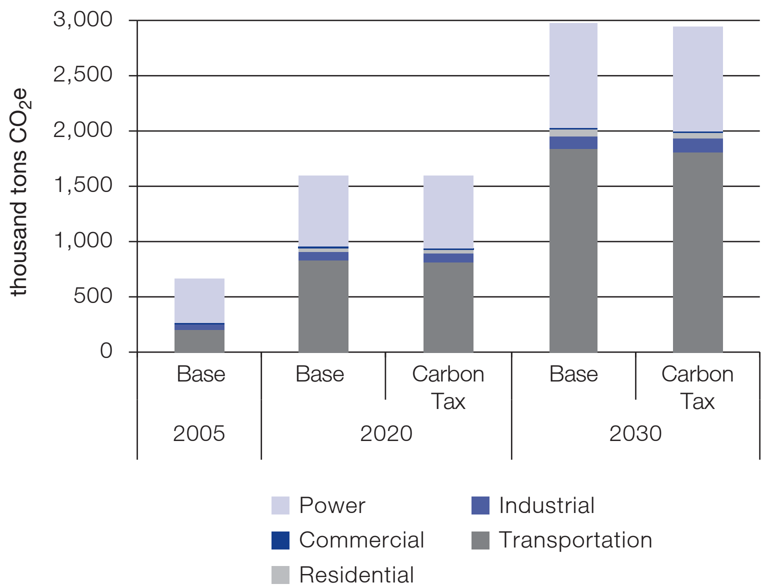
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LPG = liquefied petroleum gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

The Maldives

- Under the base case, total GHG emissions from energy use would increase about three-fold from 679,000 t CO_2e in 2005 to 2.98 million t CO_2e by 2030, with major contributions shifting from the power sector in 2005 to the transport sector in 2030 (Figure A1.5).
- With carbon tax, cumulative GHG emissions during 2005–2030 would decline by 0.41% (about 195,100 t CO_2e) from the base case level. The low level of GHG mitigation under a carbon tax regime is mainly due to the country's relatively low wind power potential, which would already be fully exploited in the base case. That is, the Maldives has no additional scope for wind power to reduce GHG emissions under a carbon-tax scenario with its current wind power potential.[43]
- Approximately 810 t CO_2e emissions (about 0.05% of base case level) could be avoided in 2020 at no additional cost by deploying two "no-regret" cleaner and energy efficient options (Table A1.6). Among 17 cleaner technology options evaluated, replacing 60% of gasoline light vehicles with gasohol (E85) light vehicles offers the highest GHG abatement potential of 13,792 t CO_2e emissions in 2020, at a low incremental abatement cost of 2005 $1.04 per ton CO_2e (Table A1.6 and Figure A1.6).

Figure A1.5 **Sectoral GHG Emissions under the Base Case and Carbon-Tax Scenario in the Maldives**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of the Maldives (unpublished country report).

[43] This result is based on currently assessed value of the wind power potential in the Maldives (Lysen 2004). Should there be a reassessment of wind power potential leading to an increase in the total amount of the possible wind power generation, the scope for GHG emission reduction would increase in the base case and also possibly under the carbon tax scenario.

Table A1.5 **Total GHG Emission at Selected Incremental Abatement Costs, the Maldives, 2020**

		Incremental Abatement Costs ($ per ton CO_2e)								
	Base Case	**≤ 0** "(No-regret" options)	**10**	**30**	**50**	**75**	**100**	**200**	**500**	**600**
Total GHG Emissions ('000 tons CO_2e)	1,609	1,608	1,579	1,579	1,568	1,568	1,568	1,539	1,517	1,497
GHG Reduction (%)		0.05	1.89	1.89	2.59	2.59	2.59	4.38	5.75	6.96
Sectoral Shares in Total GHG Emission Abatement (%)										
Residential		55.82	1.49	1.49	4.44	4.44	4.44	2.62	2.00	
Commercial		0.00	0.00	0.00	0.00	0.00	0.00	40.66	31.02	
Transport		0.00	89.81	89.81	69.11	69.11	69.11	41.10	49.26	
Industry		0.00	0.00	0.00	5.00	5.00	5.00	2.95	8.07	
Power		44.18	8.70	8.70	21.46	21.46	21.46	12.66	9.66	

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of the Maldives (unpublished country report).

Table A1.6 **Estimated Incremental Abatement Cost (IAC) and GHG Abatement Potential of Different Cleaner Technology Options in the Maldives, 2020**

Rank	Cleaner Technology Options	Annual GHG Potential ('000 tons CO_2e)	Cumulative Annual GHG Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost (2005 $ per ton CO_2e)
1	Residential solar cooking stoves replacing 10% of kerosene cooking stoves	0.45	0.45	0.0
2	MSW-based power plant replacing 50% of diesel power plant in Thilafushi island	0.36	0.81	0.0
3	Gasohol (E85)[b] light vehicles replacing 60% of gasoline light vehicles[c]	13.79	14.60	1.0
4	Biomass-based power plant replacing 10% of diesel-based electricity generation in non-Stelco operated atolls	2.29	16.89	4.5
5	Biodiesel (B10)[d] fishing vessels replacing 80% of diesel fishing vessels in the industry sector	7.73	24.62	8.8
6	Gasohol (E85) two-wheelers replacing 80% of gasoline two-wheelers	5.77	30.39	8.9
7	Solar PV power plant replacing 5% of diesel-based electricity generation in Male and Vilingili	6.29	36.68	33.3
8	Solar/diesel hybrid[e] electricity generation technology replacing 10% of diesel-based electricity in desalination industry	2.08	38.76	41.0
9	Solar powered electric buses replacing 10% of the diesel buses	1.48	40.25	41.9
10	Efficient LED lamps replacing 50% of inefficient lamps in the residential sector	1.40	41.64	49.3
11	Solar/diesel hybrid electricity generation replacing 10% of diesel-based electricity generation in resorts	28.69	70.33	141.5
12	Biodiesel (B10) buses replacing 80% of diesel buses	0.22	70.55	197.1
13	Solar/diesel hybrid vessel replacing 5% of diesel fishing vessels in the fishing industry	5.38	75.93	250.3
14	Biodiesel (B10) vessels replacing 50% of diesel vessels in the transport sector	16.56	92.49	444.9
15	Solar/diesel hybrid vessel replacing 5% of diesel vessels in the transport sector	18.16	110.65	546.3
16	Solar home system-based lighting replacing 10% of lighting demand in the residential sector	1.40	112.04	590.1

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LED = light-emitting diode, MSW = municipal solid waste, PV = photovoltaic.

[a] The cumulative potential here refers to the total amount of GHG emission abatement that could be attained if all options with the rank of the particular option or higher are deployed. For example, the cumulative potential figure corresponding to technology options up to rank no. 2 means the sum of the GHG abatement potentials of technology options ranked 1 and 2.

[b] E85 means a fuel mixture with 85% ethanol and 15% diesel.

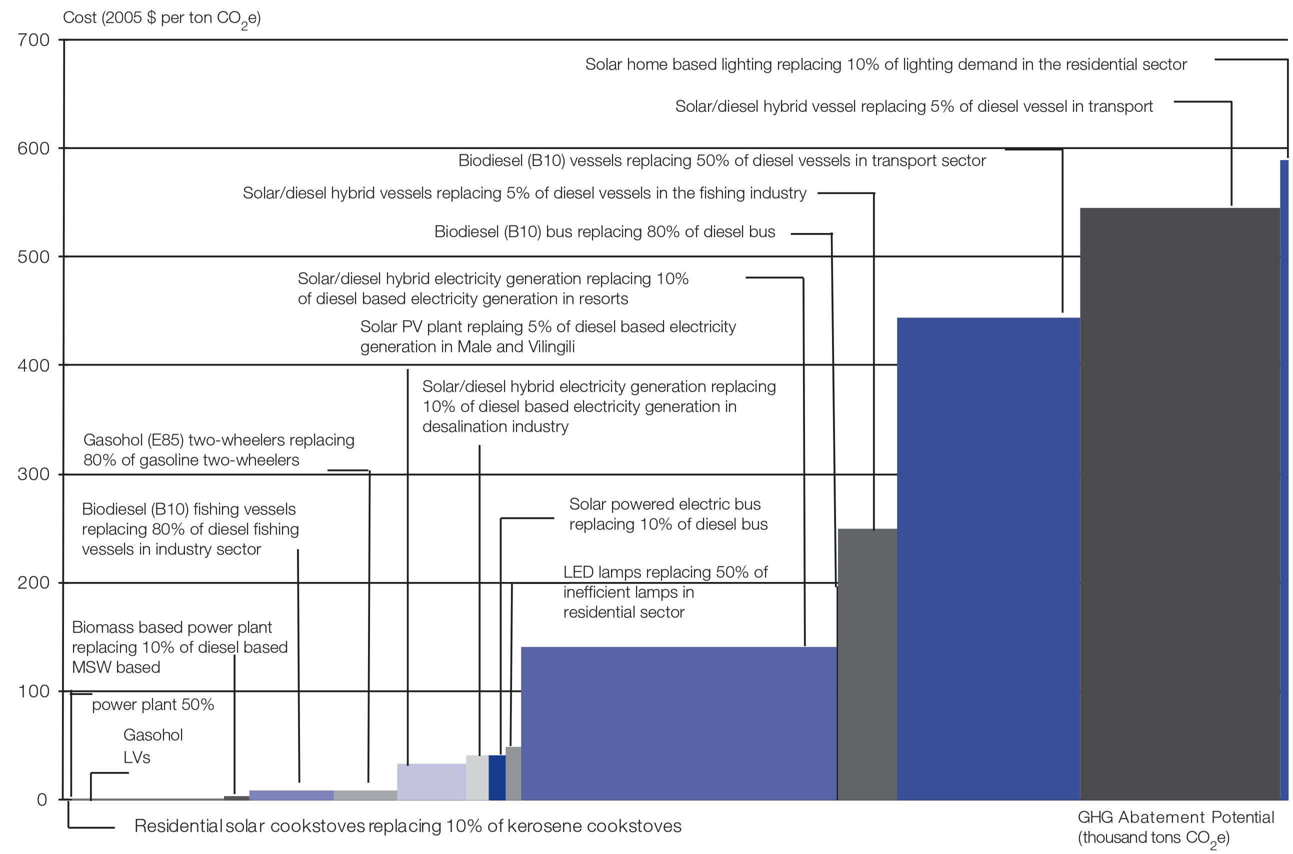
[c] Light vehicles refer to ambulance, van, jeep, car, and taxi.

[d] B10 means a fuel mixture with 10% biofuel and 90% diesel.

[e] The cost of hybrid vessel is 150.44 million $/1,000 units, which includes battery cost of 69,444.4 million $/PJ. The efficiency of the vessel is 498,000 number of units/PJ. (Source: Eaves and Eaves 2004).

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of the Maldives (unpublished country report).

Figure A1.6 **GHG Abatement Cost Curve for the Maldives, 2020**



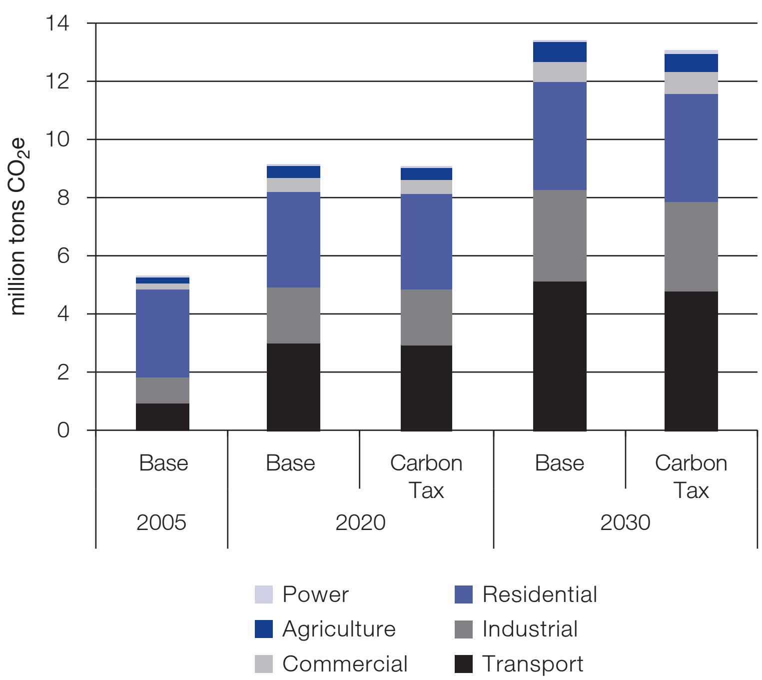
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LED = light-emitting diode, LV = light vehicle, MSW = municipal solid waste, PV = photovoltaic.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of the Maldives (unpublished country report).

Nepal

- Under the base case, total GHG emissions from energy use would increase from about 5.4 million t CO_2e in 2005 to 13.5 million t CO_2e in 2030, reflecting the country's rapid growth in fossil fuel consumption. The residential, transport, and industrial sectors are the three largest GHG emitters, with the top rank shifting from residential sector to the transport sector in 2030 (Figure A1.7).
- With carbon tax, cumulative GHG emissions during 2005–2030 would decline by 1% (about 2.0 million t CO_2e) from the base case level, while the GHG emissions in 2030 would be reduced by 2.8% (376,000 t CO_2e). The transport sector would contribute the majority (63.1%) of the cumulative reduction in GHG emissions.
- Approximately 345,000 t CO_2e emissions (about 0.05% of base case level) could be avoided in 2020 at no additional cost by deploying six "no-regret" cleaner and energy efficient options (Table A1.8). Among 13 options evaluated, replacing 50% of kerosene lamps with solar home system-based lighting offers the highest GHG abatement potential of 242,000 t CO_2e emissions in 2020, at the lowest positive incremental abatement cost of 2005 \$6.37 per ton CO_2e abated (Table A1.8 and Figure A1.8).

Figure A1.7 **Sectoral GHG Emissions under the Base Case and Carbon-Tax Scenario in Nepal**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Table A1.7 **Total GHG Emission at Selected Incremental Abatement Costs, Nepal, 2020**

		Incremental Abatement Costs ($ per ton CO_2e)							
	Base Case	≤ **0** ("No-regret" options)	**10**	**30**	**50**	**75**	**100**	**200**	**350**
Total GHG Emissions ('000 tons CO_2e)	9,248	8,903	8,661	8,661	8,661	8,588	8,549	8,464	8,413
GHG Reduction (%)		3.73	6.35	6.35	6.35	7.13	7.56	8.48	9.04
Sectoral Shares in Total GHG Emission Abatement (%)									
Power		0	41	41	41	48	45	40	38
Industry		3	2	2	2	2	2	1	1
Transport		0	0	0	0	0	6	8	14
Commercial		29	17	17	17	15	14	13	12
Residential		67	40	40	40	35	33	38	35

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Table A1.8 **Estimated Incremental Abatement Cost (IAC) and GHG Abatement Potential of Different Cleaner Technology Options in Nepal, 2020**

Rank	Cleaner Technology Options	Annual GHG Potential ('000 tons CO_2e)	Cumulative Annual GHG Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost (2005 $ per ton CO_2e)
1	Efficient stoves replacing 50% of the traditional wood stoves in residential cooking	163	163	(137.17)
2	Commercial electric stoves/ovens replacing 50% of kerosene stoves	77	239	(42.80)
3	Residential electric cooking replacing 50% of kerosene cooking	48	288	(42.38)
4	Residential electric water heaters replacing 40% of kerosene water heaters	22	309	(42.32)
5	Commercial electric water heaters replacing 40% of kerosene water heaters	24	333	(32.93)
6	Efficient diesel boilers replacing 50% of conventional diesel boilers in the industrial sector	12	345	(29.41)
7	Solar home system-based lighting replacing 50% of kerosene lamps[b]	242	587	6.37
8	Micro hydropower-based lighting replacing 25% of kerosene lamps[b]	72	660	68.07
9	Hybrid cars replacing 30% of gasoline/diesel cars in the Kathmandu valley[c]	39	699	89.33
10	Hybrid trucks replacing 30% of diesel trucks in the Kathmandu valley[c]	17	716	103.92
11	Electric buses (battery storage) replacing 20% of diesel bus service in Kathmandu	6	722	118.39
12	Residential electric space heaters replacing 50% of kerosene space heaters	62	784	118.77
13	Electric railways meeting 25% of bus services demand in the rest of Nepal (i.e., excluding the Kathmandu valley)[d]	52	836	335.88

( ) = negative, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

[a] The cumulative potential here refers to the total amount of GHG emission abatement that could be attained if all options with the rank of the particular option or higher are deployed. For example, the cumulative potential figure corresponding to technology options up to rank no. 2 means the sum of the GHG abatement potentials of technology options ranked 1 and 2.

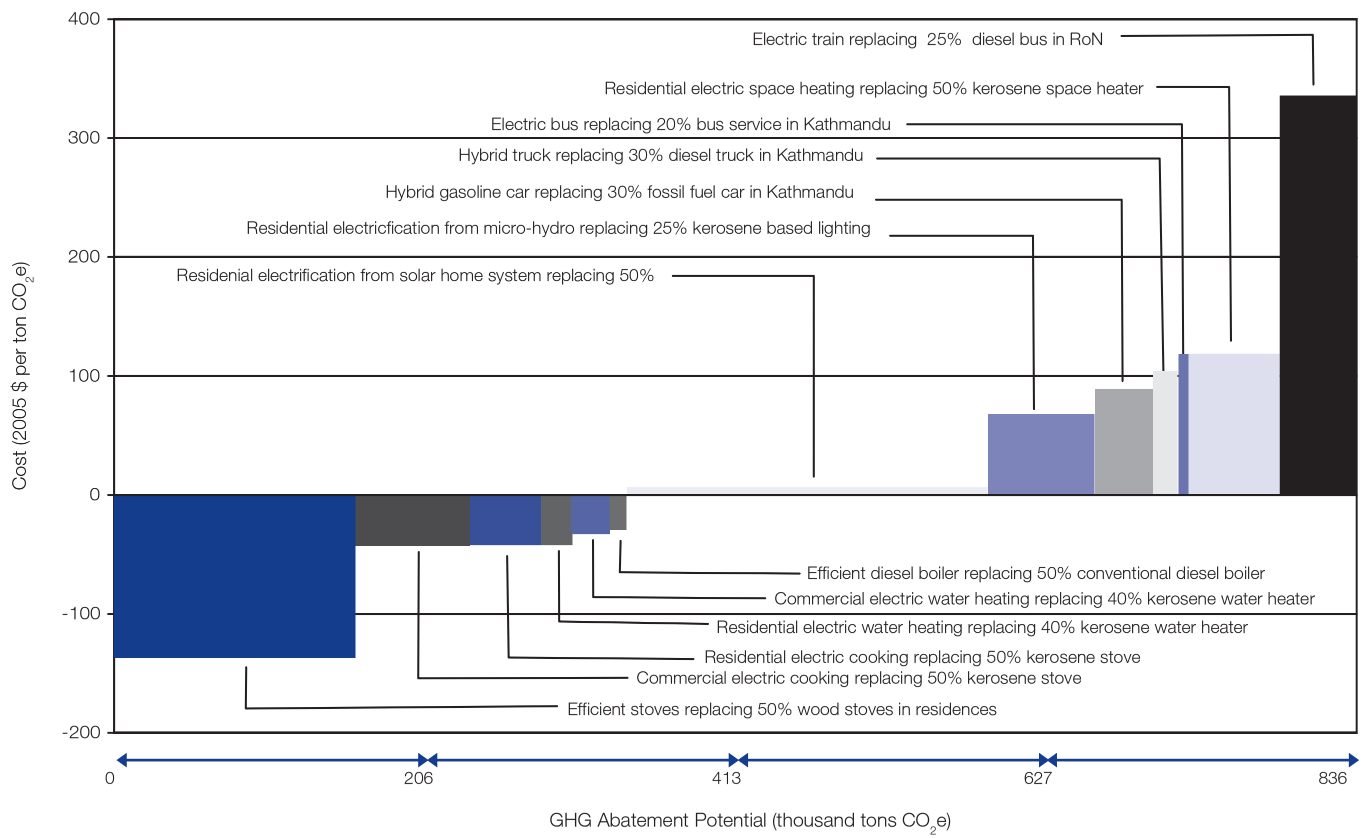
[b] Kerosene lamp is considered to be substituted by 13-W compact fluorescent lamp bulbs for solar home system and 40-W incandescent bulb for micro-hydro-based lighting.

[c] Hybrid trucks and cars considered here are based on 50% electricity and 50% diesel.

[d] Electric passenger railway is assumed to operate at an average speed of 100 km/h, seating capacity of 525 per locomotive and occupancy rate of 60%.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Figure A1.8 **GHG Abatement Cost Curve for Nepal, 2020**



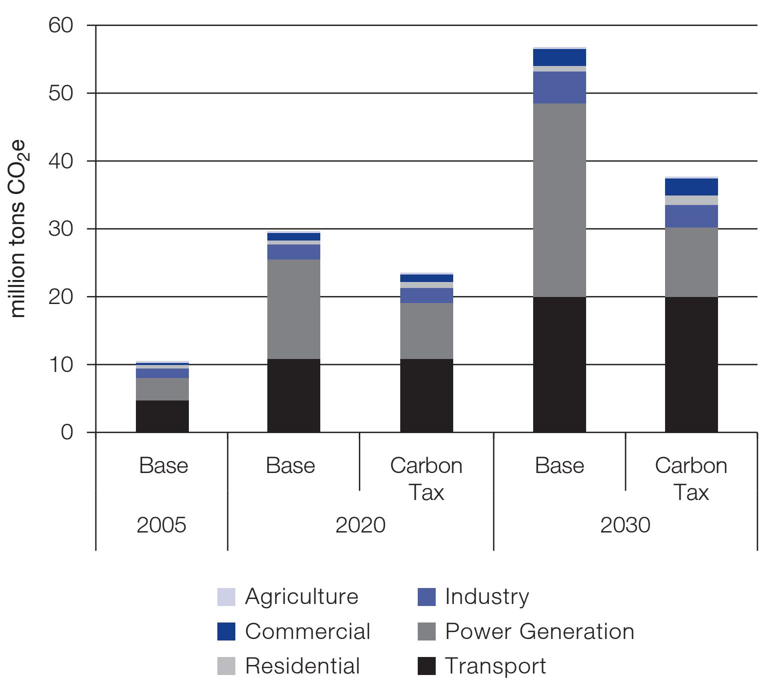
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, RoN = rest of Nepal (i.e., excluding the Kathmandu valley).

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Sri Lanka

- Under the base case, the estimated annual total GHG emissions would increase five-fold from 10.5 million t CO_2e in 2005 to 57.1 million t CO_2e in 2030, reflecting the country's rapid growth in fossil fuel consumption. The transport and power sectors account for the bulk of these emissions in both years (Figure A1.9).
- With carbon tax, cumulative GHG emissions during 2005–2030 would decline by 21.8% (186 million t CO_2e) from the base case level. GHG emissions from the industrial and power sectors in 2030 would be reduced by 11.4% and 46% respectively. The power sector would contribute 96% in the reduction of GHG emissions, while the residential, commercial, and agricultural sectors would have negligible shares.
- Approximately 2.46 million t CO_2e emissions could be avoided in 2020 at no additional cost by deploying 10 "no-regret" cleaner and energy efficient options (Table A1.10). Among 19 options evaluated, replacing conventional coal-based power generation with a 300-MW capacity of carbon capture and storage (CCS), Integrated Gasification Combined Cycle, at a low incremental abatement cost of about 2005 $6.00 per ton CO_2e abated (Table A1.10 and Figure A1.10).

Figure A1.9 **Sectoral GHG Emissions under the Base Case and Carbon-Tax Scenario in Sri Lanka**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Sri Lanka (unpublished country report).

Table A1.9 **Total GHG Emission at Selected Incremental Abatement Costs, Sri Lanka, 2020**

		Incremental Abatement Costs ($ per ton CO_2e)						
	Base Case	**≤ 0** ("No-regret" options)	**10**	**30**	**50**	**75**	**100**	**200**
Total GHG Emissions ('000 tons CO_2e)	29,750	27,288	24,109	23,960	23,960	23,960	23,785	23,481
GHG Reduction (%)		8.3	19.0	19.5	19.5	19.5	20.3	20.8
Sectoral Shares in Total GHG Emission Abatement (%)								
Residential		66.4	29.0	30.6	30.6	30.6	29.4	28.7
Commercial		3.9	1.7	1.7	1.7	1.7	1.6	3.1
Transport		18.4	8.1	7.8	7.8	7.8	7.5	8.3
Industry		11.2	4.9	4.9	4.9	4.9	4.7	4.6
Agriculture		0.03	0.01	0.01	0.01	0.01	0.01	0.01
Power		0.0	56.3	54.9	54.9	54.9	56.7	55.3

CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Sri Lanka (unpublished country report).

Table A1.10 **Estimated Incremental Abatement Cost (IAC) and GHG Abatement Potential of Different Cleaner Technology Options in Sri Lanka, 2020**

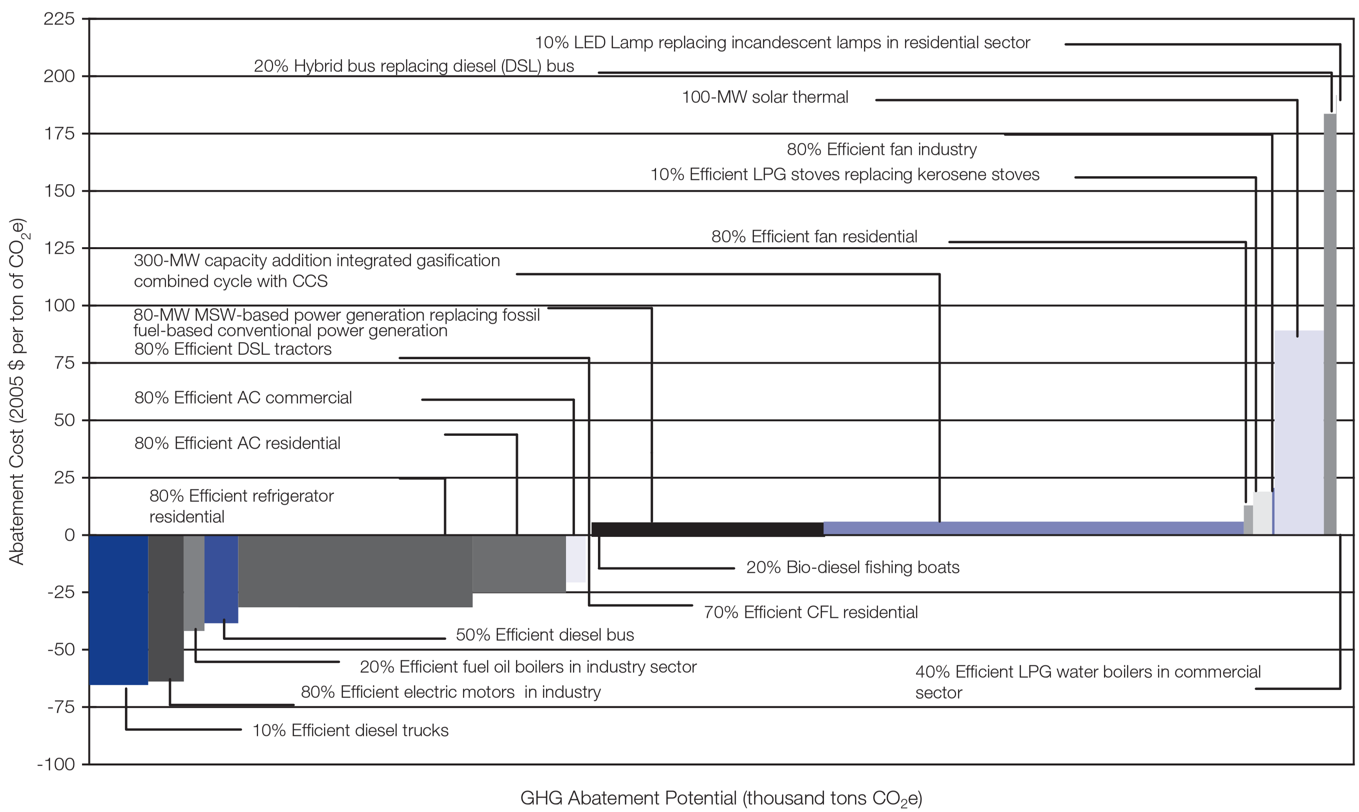
Rank	Cleaner Technology Options	Annual GHG Abatement Potential ('000 tons CO_2e)	Cumulative Annual GHG Abatement Potential[a] ('000 tons CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
1	Efficient diesel trucks replacing 10% of conventional diesel trucks	287.7	287.7	(65)
2	Efficient electric motors replacing 80% of conventional electric motors in industry sector	175.3	463.0	(64)
3	Efficient fuel oil boilers replacing 20% of conventional fuel oil boilers in industry sector	100.4	563.4	(42)
4	Efficient diesel buses replacing 50% of conventional diesel buses	166.5	729.9	(38)
5	Efficient refrigerator replacing 80% of conventional refrigerator in residential sector	1,143.9	1,873.8	(31)
6	Efficient AC replacing 80% of conventional AC in residential sector	455.3	2,329.1	(25)
7	Efficient AC replacing 80% of conventional AC in commercial sector	97.2	2,426.3	(21)
8	Efficient diesel tractor replacing 80% of conventional diesel tractors in agricultural sector	0.8	2,427.1	0
9	Efficient CFLs replacing 70% of conventional lamps (incandescent, fluorescent and kerosene lamps) in the residential sector	35.4	2,462.5	0
10	Biodiesel fishing boats replacing 20% of diesel fishing boats in the agricultural sector	0.01	2,462.5	0
11	A 80-MW MSW-based power generation replacing 3% of fossil fuel-based conventional power generation	1,126.6	3,589.1	5
12	A 300-MW capacity addition of Integrated Gasification Combined Cycle with CCS replacing conventional coal-based power generation	2,052.2	5,641.3	6
13	Efficient fan replacing 80% of conventional fan in residential sector	45.6	5,686.9	13
14	Efficient LPG stoves replacing 10% of kerosene stoves in the residential sector	93.8	5,780.7	19
15	Efficient fan replacing 80% of conventional fan in the industry sector	9.6	5,790.3	21
16	A 100-MW solar thermal capacity addition replacing 9% of power generation	241.6	6,031.9	89
17	Hybrid buses replacing 20% of diesel buses	60.9	6,092.8	184
18	LED lamps replacing 10% of incandescent lamps in the residential sector	1.0	6,093.8	192
19	Efficient LPG water boilers replacing 40% of conventional fuel oil boilers in commercial sector	92.1	6,185.9	193

( ) = negative, AC = air conditioner, CCS = carbon capture and storage, CFL = compact fluorescent lamp, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, LED = light-emitting diode, LPG = liquefied petroleum gas, MSW = municipal solid waste, MW = megawatt.

[a] The cumulative potential here refers to the total amount of GHG emission abatement that could be attained if all options with the rank of the particular option or higher are deployed. For example, the cumulative potential figure corresponding to technology options up to rank no. 2 means the sum of the GHG abatement potentials of technology options ranked 1 and 2.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Sri Lanka (unpublished country report).

Figure A1.10 **GHG Abatement Cost Curve for Sri Lanka, 2020**



AC = air conditioner, CCS = carbon capture and storage, CFL = compact fluorescent lamp, CNG = compressed natural gas, CO_2e = carbon dioxide equivalent, DSL = diesel, GHG = greenhouse gas, LED = light-emitting diode, LPG = liquefied petroleum gas, MSW = municipal solid waste, MW = megawatt.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1] – The Case of Sri Lanka (unpublished country report).

Appendix 2

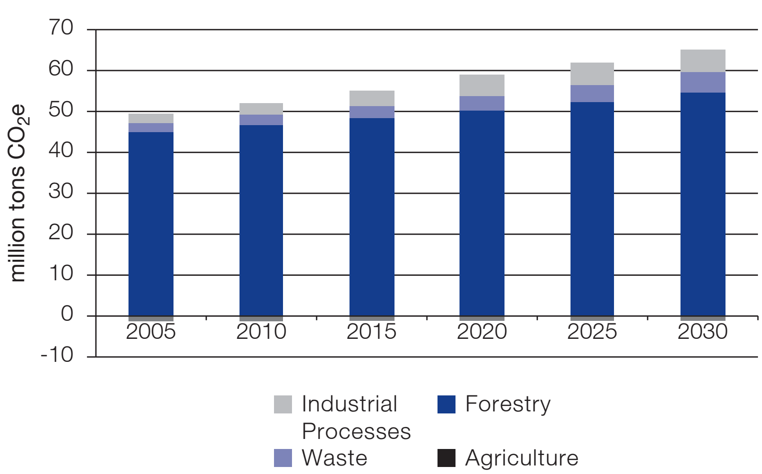
Country Summaries—GHG Emission Abatement Options and Costs in Activities Not Using Energy

GHG Emissions in 2005–2030

Bangladesh

- Total greenhouse gas (GHG) emissions would increase by around 33% from 48 million tons carbon dioxide equivalent (t CO_2e) in 2005 to to 64 million t CO_2e in 2030, of which 85.3% would come from the agriculture sector. The shares of the waste disposal and industrial processes sectors in the country's total GHG emissions would increase during the period, while carbon sequestration from the forestry sector would decline by about 11.2%.
- Among activities within the agricultural sector, methane emissions from rice cultivation contribute the major share, although by 2030 they would be surpassed by emissions from livestock enteric fermentation.
- GHG emissions from industrial processes would rise by 138% during 2005–2030, most of which would come from ammonia production.

Figure A2.1 **GHG Emissions by Sector, Bangladesh, 2005–2030**



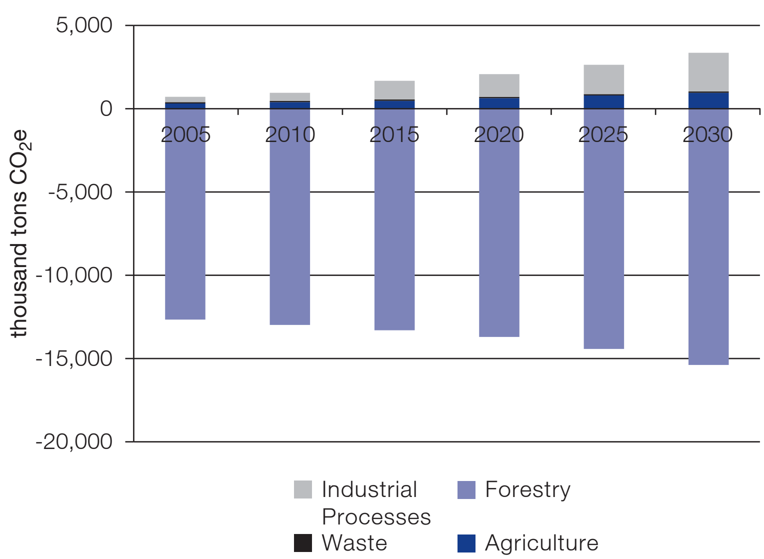
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Bhutan

- Total GHG emissions from activities not using energy (except forestry sector) would increase by 381% from 712,000 t CO_2e in 2005 to 3.43 million t CO_2e in 2030. The share of industrial processes would significantly increase from 39% in 2005 to 69% in 2030, while those of agriculture and waste disposal sectors would decline. Carbon sequestration from the forestry sector would increase by about 21.8%.
- During the base year, the largest GHG emissions from the agricultural sector are seen coming from enteric fermentation and rice cultivation.
- From the industrial processes sector, the largest CO_2 emissions would come from cement production, with growing contribution from calcium carbide and ferrosilicon production.

Figure A2.2 **GHG Emissions by Sector, Bhutan, 2005–2030**



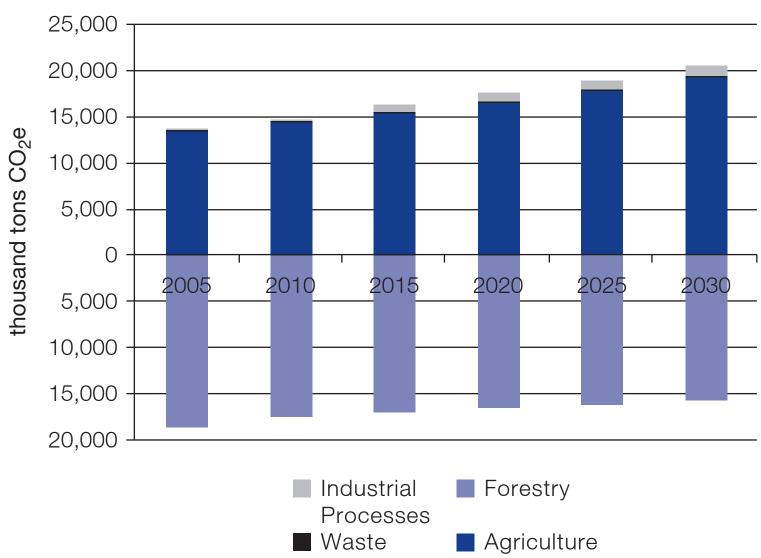
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

Nepal

- Total GHG emissions from activities not using energy (except forestry sector) would increase by 49% from 13.8 million t CO_2e in 2005 to 20.6 million t CO_2e in 2030. The share of industrial processes would increase from 1% in 2005 to 6% in 2030, while that of the agriculture sector would decline; contributions from the waste disposal sector would remain relatively stable at around 1%. Carbon sequestration from the forestry sector would decline by about 15.8% during the period.
- The largest GHG emissions from the agricultural sector are seen coming from enteric fermentation and rice cultivation, with emissions from manure management and agricultural soils expected to gradually increase until 2030.
- CO_2 emissions from cement production are expected to grow with the anticipated growth in gross domestic product. It is estimated to increase by 583%, from 168,000 t CO_2e in 2005 to 1.14 million t CO_2e in 2030.

Figure A2.3 **GHG Emissions by Sector, Nepal, 2005–2030**



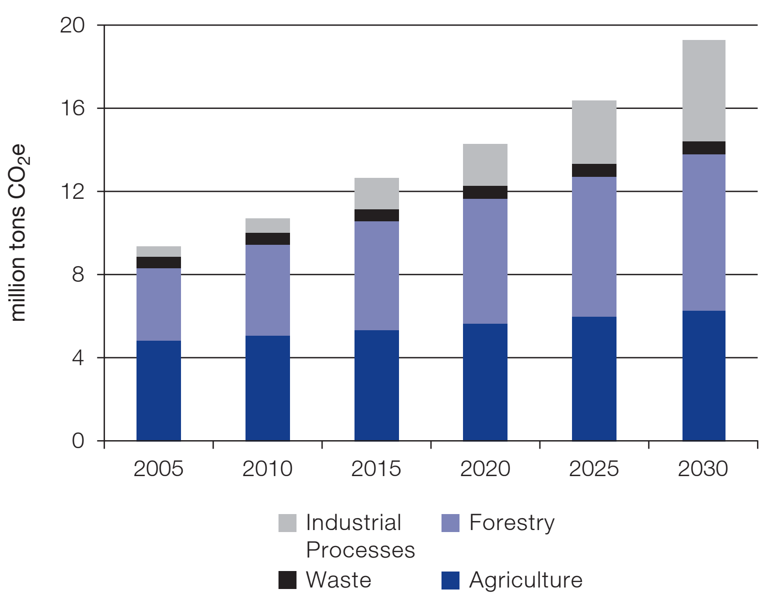
CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Sri Lanka

- Total GHG emissions from activities not using energy would increase from 9.4 million t CO_2e in 2005 to 19.3 million t CO_2e in 2030 (or by around 106%) during 2005–2030. The share of industrial processes would increase almost 10-fold, providing 25% of total GHG emissions in 2030. GHG emissions from the agriculture sector would decline, while those from the waste disposal sector would remain relatively stable at around 600,000 t CO_2e during the period. The share of the forestry sector in total GHG emissions would increase from 37% in 2005 to 39% in 2030.
- In the agricultural sector, rice cultivation, enteric fermentation, and agricultural soils would be the largest GHG emitters, with emissions from manure management and field burning of agricultural residues expected to gradually increase until 2030.
- From the industrial processes sector, the largest CO_2 emissions would come from clinker and lime production, followed by steel production. The contribution of clinker and lime production to the sector's total GHG emissions in Sri Lanka would increase from 83% in 2005 to 99% in 2030.

Figure A2.4 **GHG Emissions by Sector, Sri Lanka, 2005–2030**



CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Sri Lanka (unpublished country report).

GHG Emission Reduction Potential and Abatement Costs in 2020

Bangladesh

Sector/Abatement Option	Total GHG Abatement Potential 2005–2030 (ton CO_2e)	GHG Abatement Potential in 2020 (ton CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
Agriculture			
1. Urea-molasses multi-nutrient blocks (UMMB)	490,442	20,770	14.16
2. Urea-treated straw (UTS) feeding for local (indigenous) dairy cattle	1,374,723	58,219	45.99
3. Flood regulation through multiple aerations	729,837	30,740	13.26
4. Draining fields twice in rainfed, flood-prone, and deep water (50–100 cm water level) rice land	6,493,586	275,042	15.72
Forestry			
5. Conserving existing carbon pools/sinks	–	1,096,778	0.58
6. Expanding the amount of carbon stored (stocks)	–	4,621,878	14.71
Waste Generation			
7. Recycling	–	508,781	3.79
8. Composting of municipal solid wastes (MSW)	–	737,473	1.20
Industrial Processes			
9. Post-combustion carbon capture and storage (CCS) in cement production	–	390,467	155.78
10. Oxy-combustion CCS in cement production	–	263,692	153.74

– = no analysis, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bangladesh (unpublished country report).

Bhutan

Sector/Abatement Option		Total GHG Abatement Potential 2005–2030 (ton CO_2e)	GHG Abatement Potential in 2020 (ton CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
Agriculture				
1.	Urea-molasses multi-nutrient blocks (UMMB)	12,175	1,624	13.50
2.	Urea-treated straw (UTS) feeding for local (indigenous) dairy cattle	56,664	2,039	43.66
3.	Flood regulation through multiple aerations	91,371	3,848	4.21
4.	Draining fields twice in rainfed, flood-prone, and deep water (50–100 cm water level) rice land	–	–	–
Forestry				
5.	Conserving existing carbon pools/sinks	–	464,446	194.79
6.	Expanding the amount of carbon stored (stocks)	–	31,210	642.96
Waste Generation				
7.	Recycling	–	11,146	1.18
8.	Composting of municipal solid wastes (MSW)	–	16,156	0.42
Industrial Processes				
9.	Post-combustion carbon capture and storage (CCS) in cement production	–	383,845	139.05
10.	Oxy-combustion CCS in cement production	–	259,220	137.24

– = no analysis, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Bhutan (unpublished country report).

Nepal

Sector/Abatement Option	Total GHG Abatement Potential 2005–2030 (ton CO_2e)	GHG Abatement Potential in 2020 (ton CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
Agriculture			
1. Urea-molasses multi-nutrient blocks (UMMB)	1,219,911	48,941	13.67
2. Urea-treated straw (UTS) feeding for local (indigenous) dairy cattle	–	–	–
3. Flood regulation through multiple aerations	21,138,621	849,080	3.01
4. Draining fields twice in rainfed, flood-prone, and deep water (50–100 cm water level) rice land	–	–	–
Forestry			
5. Conserving existing carbon pools/sinks	–	8,913,098	1.17
6. Expanding the amount of carbon stored (stocks)	–	30,133	38.62
Waste Generation			
7. Recycling	–	18,027	3.32
8. Composting of municipal solid wastes (MSW)	–	26,130	0.59
Industrial Processes			
9. Post-combustion carbon capture and storage (CCS) in cement production	–	390,467	155.78
10. Oxy-combustion CCS in cement production	–	263,692	153.74

– = no analysis, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Nepal (unpublished country report).

Sri Lanka

Sector/Abatement Option		Total GHG Abatement Potential 2005–2030 (ton CO_2e)	GHG Abatement Potential in 2020 (ton CO_2e)	Incremental Abatement Cost ($ per ton CO_2e)
Agriculture				
1.	Urea-molasses multi-nutrient blocks (UMMB)	273,038	29,810	14.66
2.	Urea-treated straw (UTS) feeding for local (indigenous) dairy cattle	–	–	–
3.	Flood regulation through multiple aerations	1,174,117	49,452	25.03
4.	Draining fields twice in rainfed, flood-prone, and deepwater (50–100 cm water level) rice land	–	–	–
Forestry				
5.	Conserving existing carbon pools/sinks	–	4,966,190	4,81
6.	Expanding the amount of carbon stored (stocks)	–	3,438,966	20.65
Waste Generation				
7.	Recycling	–	82,309	5.48
8.	Composting of municipal solid wastes (MSW)	–	119,307	1.98
Industrial Processes				
9.	Post-combustion carbon capture and storage (CCS) in cement production	–	390,467	155.78
10.	Oxy-combustion CCS in cement production	–	263,692	153.74

– = no analysis, CO_2e = carbon dioxide equivalent; GHG = greenhouse gas.

Source: Regional Economics of Climate Change in South Asia (Part I: Study of Cleaner Technologies and Options) [RECCSA1]—The Case of Sri Lanka (unpublished country report).

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Economics of Reducing Greenhouse Gas Emissions in South Asia
Options and Costs

Against a backdrop of increasing emission of greenhouse gases (GHGs) that are responsible for global climate change, the South Asia developing member countries (DMCs) of the Asian Development Bank have been witnessing a steady rise in fossil fuels and energy consumption and demand, keeping pace with their economic growth. The region's major challenge is how to achieve sustained and rapid economic growth for reducing poverty while reducing the overall intensity of energy use, increasing energy efficiency, and substituting to cleaner energy. This report synthesizes the results of national studies on options and costs of reducing GHG emissions in five South Asia DMCs—Bangladesh, Bhutan, the Maldives, Nepal, and Sri Lanka. It examines the economics of cleaner technologies that promote low-carbon development and climate change mitigation, identifies constraints and barriers that reduce incentives to invest in GHG emission-reducing technologies, and recommends actions and enabling conditions to overcome the barriers.

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